PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H02K 39/08, 15/00, 15/12, H01R 39/16, 39/04, 39/06, 43/06

A1

(11) International Publication Number: WO 99/57797

(43) International Publication Date: 11 November 1999 (11.11.99)

(21) International Application Number: PCT/US99/09579

(22) International Filing Date: 30 April 1999 (30.04.99)

(30) Priority Data:
09/070,977 1 May 1998 (01.05.98) US

(71) Applicant: McCORD WINN TEXTRON, INC. [US/US]; 615 Harvey Road, Manchester, NH 03103 (US).

(72) Inventors: ZIEGLER, William, A.; 92 Hartshorn Street, Reading, MA 01867 (US). BAUER, William, A.; 127 Parkway Road, St. Mary's, PA 15857 (US).

(74) Agent: JONES, Eric, T.; Reising, Ethington, Barnes, Kisselle, Learman & McCulloch, P.C., P.O. Box 4390, Troy, MI 48099 (US).

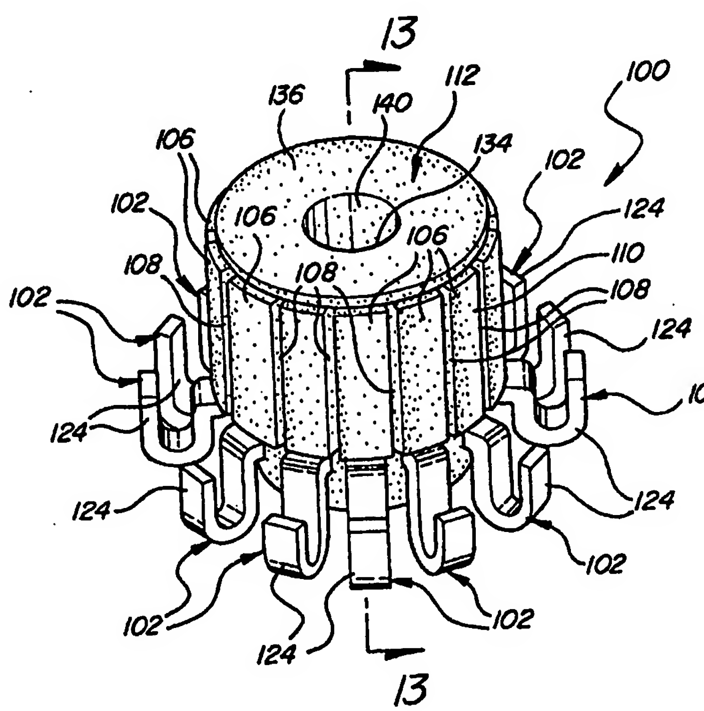
(81) Designated States: CA, CN, JP, MX, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: CARBON COMMUTATOR

(57) Abstract

A barrel-type carbon-segment commutator assembly (100) for an electric motor includes an annular array of copper conductor sections (102) stamped from a single copper blank. The annular array is overmolded with an electrical-conducting resin-bonded carbon composition (106) that mechanically interlocks the conductor sections and defines an outer cylindrical commutating surface (110). An annular hub (112) is then formed by overmolding an insulator material inside, under, and above the carbon overmold and the conductor section array. The hub insulator material flows into the radial grooves (108) of the carbon overmold and leaves only the outer cylindrical commutating surface exposed.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		
EE	Estonia						

CARBON COMMUTATOR

This is a continuation in part of U.S. Application Serial Number 08/937,307 filed October 3, 1997.

TECHNICAL FIELD

This invention relates generally to a carbon-segment commutator for an electric motor and a method for its manufacture.

BACKGROUND OF THE INVENTION

Permanent magnet direct current motors are sometimes used for submerged fuel pump applications. These motors typically employ either face-type commutators or cylinder or "barrel"-type commutators. Face-type commutators have planar, circular commutating surfaces disposed in a plane perpendicular to the axis of armature rotation. Barrel-type commutators have arcuate, cylindrical commutating surfaces disposed on the outer side surface of a cylinder that is positioned coaxially around the axis of armature rotation. Regardless of their commutating surface configurations, electric motors used in submerged fuel pump applications must be small and compact, have a long life, be able to operate in a corrosive environment, be economical to manufacture and operate and be essentially maintenance-free.

Submerged fuel pump motors must sometimes operate in a fluid fuel medium containing an oxygen compound, such as methyl alcohol and ethyl alcohol. The alcohol increases the conductivity of the fuel and, therefore, the efficiency of an electrochemical reaction that deplates any copper motor components that are exposed to the fuel. For this reason, carbon and carbon compositions are sometimes used to form carbon segments with segmented commutating surfaces for the motors. This is because carbon commutators do not corrode or "deplate", as copper commutators do. Commutators with carbon

segments also typically include metallic contact sections that are in electrical contact with the carbon segments and provide a terminal for physically connecting each electrical contact to an armature coil wire.

It is known to form a carbon commutator by first molding and heat treating a moldable carbon compound or machining heat-treated carbon or carbon/graphite stock. Such an arrangement is shown in German Disclosure 3150505.8. A commutator-insulating hub may then be formed to support the metallic substrate. The hub may be molded directly to the metallic substrate either before or after the carbon is bonded to the metallic substrate. Slots are then machined through the carbon article and the metallic substrate to separate the carbon article and substrate into a number of electrically isolated segments. An inner diameter, outer diameter and the commutating surface of the commutator may also need to be machined.

After the completed commutator is assembled to an armature, a clamshell mold may be positioned over the newly assembled commutator-armature in a final overmolding process. With face-type commutators, an open end of the clam shell mold is made to seal around the commutator in a manner that leaves the commutating surface exposed. Insulator material is then injected into the clam shell mold. Once the insulator material has cured, the clam shell mold is removed. This final overmolding step protects copper armature windings and other corrosion-prone elements from chemically reacting with ambient fluids such as oxygenated fuels. The overmolding also secures wires to reduce potential for stress failures and to maintain a corrected dynamic balance level. Overmolding will also reduce windage losses in the pump.

When, in manufacturing a carbon commutator with a metallic substrate, cuts are machined into or through the metallic substrate, metal chips may be produced. These metal chips can lodge in the slots between carbon segments causing electrical failures. Machining into a metallic substrate can also expose the cut portions of the substrate to the corrosive effects of oxygenated fuels.

Where the carbon and metal substrate portions of a commutator are machined-through to form electrically isolated segments, some type of support

structure must be provided to strengthen the commutator and mechanically bind the carbon segments and conductor sections together. Such support structures sometimes require substantial additional axial space for the commutator, which can increase the overall axial length of the armature-commutator assembly and or reduce the size and the quantity of wire wound in the armature.

For some types of electrical-conducting resin-bonded carbon compositions, an insulating surface skin characteristically forms on exterior surfaces of the composition as it cures. This skin forms an impediment to electrical contact between the carbon composition and the metallic conductor sections. Therefore, a carbon commutator using such a composition must provide an electrical path through the insulating surface skin.

One approach to solving these problems is disclosed in United States Patent Number 5,386,167 issued January 31, 1995 to Strobi (the Strobi patent). The Strobi patent shows a face-type commutator having eight carbon segments formed from an electrical-conducting resin-bonded carbon composition. To avoid problems associated with machining into metal substrates, the carbon segments are formed by overmolding a carbon disk onto eight pie-piece-shaped copper segments then radially cutting between the segments to form the electrically isolated carbon segments. A plastic substrate holds the copper segments in position for carbon overmolding and provides mechanical interlock between the carbon segments. However, the plastic substrate increases the axial thickness of the commutator. In addition, the Strobi patent does not provide structures that would provide an electrical path through carbon composition skinning or structures that might otherwise reduce electrical resistance.

U.S. Patent No. 4,358,319 issued November 9, 1982 to Yoshida et al. discloses a barrel-type carbon commutator assembly that includes an annular cylindrical array of carbon segments. Each carbon segment has an outer semi-circumferential side surface for making physical and electrical contact with a brush. A retention groove extends around an inner circumferential surface of the carbon segment array. The carbon segments are electrically isolated from each other by longitudinal cuts. A hub comprising insulating material is disposed within the

annular carbon segment array and engages the retention groove at the top end of each carbon segment.

To manufacture this commutator Yoshida et al. discloses a method that includes the steps of forming an annular carbon cylinder with a retention groove, over-molding the carbon cylinder with insulator material to form a hub and machining slots in the over-molded barrel to form electrically isolated barrel segments. The electrical connections between carbon segments and coil wires are made by soldering or gluing the wires directly to the carbon segments themselves.

A fuel pump supplied by Bosch to Mercedes Benz shows a barrel-style commutator that includes a cylindrical commutating surface formed by a cylindrical array of carbon segments. Radial inner surfaces of the carbon segments form a composite inner circumferential surface of the carbon segment array. The carbon segments are electrically connected to respective coil wires by copper substrate sections soldered to the respective radial inner surfaces of the carbon segments. Each copper substrate section includes a terminal for supporting the end of a coil wire.

The Bosch commutator appears to be formed by fitting and soldering a tube portion of a copper substrate to the inner circumferential surface of the carbon cylinder. Radial cuts are then made to form and electrically isolate the carbon segments and copper substrate sections from each other. An over-molded insulator holds the carbon segments and copper substrate sections together. This process requires that a copper substrate be fabricated to include wire terminals and a tube portion closely toleranced to fit within the inner circumferential surface of the carbon cylinder. The Bosch process also requires that a difficult soldering operation be performed between the inner circumferential surface of the carbon cylinder and the outside diameter of the copper tube.

U.S. Patent No. 5,255,426 issued October 26, 1993 to Farago et al. discloses a face-type carbon commutator manufactured by first forming an annular or torroidal carbon cylinder comprising fine-grained electrical-grade carbon. Next, a cylinder base end surface is plated with a layer of nickel. A layer of copper is then plated over the nickel plating. The plated base end surface of

the cylinder is then soldered to a stamped and formed copper substrate mounted on a pre-molded hub. Lateral slots are then machined axially downward into a top commutating surface opposite the base surface of the carbon cylinder. The slots are cut axially through the carbon and the copper substrate to form the electrically isolated carbon/copper commutator sectors. After the slots are machined, the pre-molded hub continues to hold the electrically isolated commutator sectors together.

What are needed are both face and barrel-type carbon-segment commutators that are stronger and provide lower electrical resistance through improved electrical contact between carbon segments and metallic substrates. Also needed are methods for manufacturing such commutators that are quick, easy and inexpensive.

SUMMARY OF THE INVENTION

According to the invention, a carbon-segment commutator assembly for an electric motor is provided. The commutator assembly comprises an annular array of at least two circumferentially spaced conductor sections arranged around a rotational axis. The assembly also includes an annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition. Each carbon segment is overmolded onto at least one surface of a corresponding one of the conductor sections. The annular array defines a segmented commutating surface of the commutator. An overmolded insulator hub is disposed around and between the carbon segments. The insulator hub mechanically interlocks the carbon segments and includes an outer surface. Characterizing the invention is that each conductor section has at least one conductor projection that is at least partially embedded in a corresponding one of the overmolded carbon segments. The embedded conductor projections reduce electrical resistance by increasing surface area contact between each conductor section and its corresponding carbon segment.

BRIEF DESCRIPTION OF THE DRAWINGS

To better understand and appreciate the invention, refer to the following detailed description in connection with the accompanying drawings:

Figure 1 is a top view of a carbon face-type commutator assembly constructed according to the present invention;

Figure 2 is a cross-sectional view of the commutator assembly of Fig. 1 taken along line 2-2;

Figure 2A is a cross-sectional view of an alternative commutator assembly construction to that shown in Fig. 2;

Figure 3 is a side view of the commutator assembly of Fig. 1;

Figure 4 is a top view of an array of copper conductor sections stamped from a square copper blank for forming a face-type commutator in accordance with the present invention;

Figure 5 is a side view of the stamped copper blank of Fig. 4;

Figure 6 is a top view of a carbon composition ring overmolded onto the stamped copper blank of Fig. 5 in accordance with the present invention;

Figure 7 is a cross-sectional side view of the carbon overmolded stamped blank of Fig. 6 taken along line 7-7 of Fig. 6;

Figure 8 is a bottom view of the carbon overmolded stamped blank of Fig. 6;

Figure 9 is a partial cross-sectional, partially cut-away perspective view of a clamshell mold positioned around an armature assembled to a commutator assembly constructed according to the present invention;

Figure 10 is a perspective view of an alternative conductor section constructed according to the present invention;

Figure 11 is a top view of an alternative conductor section tang constructed according to the present invention;

Figure 12 is a perspective view of a barrel-type commutator constructed according to the invention;

Figure 13 is a cross-sectional front view of the commutator of Fig. 12 taken along line 13-13 of Fig. 12;

Figure 14 is a cross-sectional top view of the commutator of Fig. 12 taken along line 14-14 of Fig. 13;

Figure 15 is a magnified fragmentary view of plated metal layers on a bottom end surface of a carbon segment of the barrel-type commutator of Fig. 12 or the face-type commutator of Fig. 30;

Figure 16 is a top view of a substrate portion of the commutator of Fig. 12;

Figure 17 is a cross-sectional front view of the substrate of Fig. 16;

Figure 18 is a cross-sectional front view of a carbon cylinder portion of the commutator of Fig. 12 connected to the substrate portion of the commutator of Fig. 12;

Figure 19 is top view of the cylinder and substrate of Fig. 18;

Figure 20 is a top view of an alternative embodiment of the cylinder and substrate of Fig. 18;

Figure 21 is a top view of an alterriative barrel-type carbon commutator assembly constructed according to the present invention;

Figure 22 is a front view of the alternative barrel-type carbon commutator assembly of Fig. 21;

Figure 23 is a cross-sectional view of the commutator assembly of Fig. 21 taken along line 23-23;

Figure 24 is a top view of an array of copper conductor sections stamped from a square copper blank for forming a barrel-type commutator in accordance with the present invention;

Figure 25 is a top view of a carbon composition ring overmolded onto the stamped copper blank of Fig. 24 in accordance with the present invention;

Figure 26 is a cross-sectional side view of the carbon overmolded stamped blank of Fig. 25 taken along line 26-26 of Fig. 25;

Figure 27 is a top view of the carbon overmolded stamped blank of Fig. 25 overmolded with a hub of electrical insulating material;

Figure 28 is a cross-sectional side view of the insulator overmolded, carbon overmolded stamped blank of Fig. 27 taken along line 28-28 of Fig. 27;

Figure 29 is a top view of an alternative carbon face-type commutator assembly constructed according to the present invention;

Figure 30 is a cross-sectional view of the commutator assembly of Fig. 29 taken along line 30-30 of Fig. 29; and

Figure 31 is a magnified view of a soldered bond between a metallized layer of carbon and a copper substrate shown in Fig. 13 and Fig. 30.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

A planar face-type overmolded carbon-segment commutator assembly for an electric motor is generally shown at 12 in Figs. 1-3 and 9. A barrel-type embodiment of an overmolded carbon-segment commutator assembly is shown at 12c in Figs. 21-23. Unless indicated otherwise, portions of the following description of features of the face-type commutator assembly shown in Figs. 1-8 apply equally to like-numbered features of the barrel-type embodiment shown in Figs. 21-28. Features of the barrel-type embodiment shown in Figs. 21-28 will bear the suffix "c" when corresponding features of the face-type commutator are shown in Figs. 1-8.

The face-type commutator assembly 12 comprises an annular array of eight circumferentially spaced conductor sections, generally indicated at 14 in Figs. 1-11. Each conductor section 14 is a thin, flat, roughly triangular piece of copper. The conductor sections 14 are arranged around a commutator rotational axis 16 as shown in Figs. 1-9. Each conductor section 14 has the same general sectorial configuration as all the other conductor sections 14. In other words, and as best shown in Fig. 4, each conductor section 14 has the shape of a pie piece cut from a circular, radially-cut pie.

As generally indicated in Figs. 1, 2, 8 and 9, the commutator assembly 12 also comprises an annular array of eight circumferentially spaced carbon segments 18. Each carbon segment 18 has the same general sectorial

configuration as all the other carbon segments. The segments 18 are initially formed as a single annular carbon disk as shown at 20 in Fig. 6. The carbon disk 20 is made from an electrical-conducting resin-bonded moldable conductive carbon composition before being cut into eight equal segments 18. The carbon disk 20 or "overmold" is overmolded onto the conductor section 14 array so that when the disk 20 is cut, each carbon segment 18 is left formed onto an upper surface of a corresponding one of the conductor sections 14. The annular array of carbon segments 18 has a segmented, circular upper surface 22 that serves as the segmented commutating surface of the commutator.

An overmolded insulator hub, generally indicated at 24 in Figs. 1-3, is circumferentially disposed around, under and between the carbon segments 18 and conductor sections 14. When cured, the insulator hub 24 mechanically interlocks the carbon segments 18. The insulator hub 24 has a generally cylindrical shape with a cylindrical armature shaft aperture 26 disposed coaxially along the commutator rotational axis 16. As shown in Fig. 9, the cylindrical armature shaft aperture 26 is shaped to receive an armature shaft 28.

Each conductor section 14 has two integral upturned conductor projections, shown at 30 in Figs. 4 and 5. The conductor projections 30 extend from opposing diagonal edges of an upper surface 32 of the conductor section 14. When the carbon composition is overmolded onto the conductor section 14 array, the upturned projections 30 are embedded in the overmolded mass 20. After the carbon disk 20 is cut into segments 18, each of the upturned projections 30 of each conductor section 14 remains embedded in a corresponding one of the overmolded carbon segments 18. Because of their shape and location within the carbon segments 18 the embedded projections 30 reduce electrical resistance by increasing surface area contact between each conductor section 14 and its corresponding carbon segment 18. This is discussed below in detail.

Each conductor section 14 in the conductor section 14 array includes a circular conductor section aperture, shown at 34 in Figs. 2 and 4. A conductor section aperture 34 is disposed approximately midway between an inner apex 36 and an outer semi-circumferential margin 38 of each conductor section 14.

As shown in Figs. 4 and 6-8, at the inner apex 36 of each conductor section 14 is a rectangular apex tab 40. As is best shown in Figs. 1-3, a tang 42 extends integrally and radially outward from the outer semi-circumferential margin 38 of each conductor section 14.

As shown in Figs. 4 and 5, the conductor projections 30 are bent-up portions that extend integrally upward from the conductor sections 14. Each conductor section 14 includes two such bent-up projections 30. Each bent-up projection 30 is elongated and rectangular and is bent-up (i.e., bent axially outward) from its respective conductor section 14 along a lower elongated margin.

Each conductor section 14 is embedded between the insulator hub 24 and one of the overmolded carbon segments 18. The tang 42 of each conductor section 14 protrudes radially outward from the insulator hub 24.

As is best shown in Figs. 1 and 8, each carbon segment 18 has the general shape of a piece of a radially-cut circular pie, i.e., the same general shape as each conductor section 14. However, each carbon segment 18 is longer, wider and thicker than each conductor section 14. Each carbon segment 18 has an inner apex wall 44 and an outer semi-circumferential peripheral wall 46. Both the inner apex wall 44 and the outer circumferential wall 46 of each carbon segment 18 have stair-stepped profiles which define an inner shelf-detent 48 and an outer shelf-detent 50, respectively.

The carbon segments 18 are made of an injection-molded and hardened composition of graphite powder and carrier material with the graphite powder making up 50-80% of the total composition weight. The carrier material is preferably a polyphenylene sulfide (PPS) resin. While this composition is suitable for practicing the invention, other carbon compositions known in the prior art are suitable for use in the present invention depending upon the application in which the armature is used.

In other embodiments, metal particles may be embedded in the composition of carbon powder and carrier material to reduce electrical resistance between each conductor section and its corresponding carbon segment by improving carbon segment surface conductivity. The total metal content of the

composition in such embodiments would be less than 25%. The metal particles could have one or more of a number of different configurations to include powder flakes. The metal particles would preferably be made of silver or copper.

Radial interstices, generally indicated at 52 in Figs 1, 2, 3, 7 and 8, separate the carbon segments 18. Each of the interstices 52 has an inner groove portion 54 and an outer slot portion 56. The inner groove portions 54 are formed during carbon overmolding. The outer slot portions 56 are formed by machining the commutating surface 22.

The insulator hub 24 has flat upper and lower surfaces disposed adjacent the upper and lower edges of the circumferential sidewall. The circumferential hub sidewall is disposed perpendicular to the upper and lower surfaces of the hub 24. As best shown in Fig. 2, the armature shaft aperture 26 includes upper 58 and lower 60 frusto-conical sections that taper inward from larger upper and lower outer diameters to a smaller inner diameter. An inner portion 62 of the armature shaft aperture 26 has a constant diameter, i.e., the smaller inner diameter, along its axial length.

An alternative carbon segment commutator assembly construction is generally indicated at 12a in Fig. 2A. Reference numerals with the suffix "a" in Fig. 2A indicate alternative configurations of elements that also appear in the embodiment of Fig. 2. Where a portion of this description uses a reference numeral to refer to Fig. 2, We intend that portion of the description to apply equally to elements designated by numerals having the suffix "a" in Fig. 2A. As shown in Fig. 2A, each carbon segment 18a encases one of the conductor sections 14a. This arrangement maximizes both strength and electrical contact area between each carbon segment 18a and its corresponding conductor section 14a.

The inner groove portions 54 of the interstices 52 are filled with the insulator material of the hub 24. Hub insulator material is also disposed around the circumference of the carbon segment 18 array and encases the outer shelf-detent 50 of each carbon segment 18. Hub insulator material that forms the armature shaft aperture 26 also encases the inner shelf-detent 48 of each carbon segment 18.

As is best shown in Fig. 3, the insulator hub 24 includes a circumferential land 64 that extends completely around a circumferential sidewall of the insulator hub 24. The land 64 has an axial width that extends from the protruding conductor section tangs 42 to the unfilled outer slots 56 of the interstices 52. As shown in Fig. 9, the circumferential land 64 provides a circumferential sealing surface to mate with a corresponding surface 65 of a clamshell-type mold 67. The clamshell-type mold 67 is used in a final insulation overmolding process that is explained in detail below.

The hub insulator material comprises a glass-filled phenolic available from Rogers Corporation of Manchester Connecticut under the trade designation "Rogers 660." Other materials that would be suitable for use in place of Rogers 660 include high-quality engineering thermoplastics, i.e., thermoplastics that exhibit a high degree of stability when subjected to temperature changes.

In other embodiments, the annular arrays of conductor sections 14 and carbon segments 18 may include either more or less than eight sections, respectively. Also, the carrier material of the carbon composition may comprise a phenolic resin with up to 80% carbon graphite loading, a thermoset resin or a thermoplastic resin other than PPS, such as a liquid-crystal polymer (LCP). Both PPS and phenol type resins withstand long term exposure to fuels and alcohols. Other embodiments may also employ a commutator assembly 12 of the cylindrical or "barrel" type rather than the face-type commutator shown in the figures.

In other embodiments the conductor section projections 30 may have any one or more of a large number of possible configurations designed to increase carbon to copper surface contact. For example, rather than comprising single bent-up portions of the conductor sections as shown at 14 in Figs. 4 and 5, the projections may instead comprise separate elements, crimped into place under a bent-over finger 66 extending from the conductor sections 14' as shown in Fig. 10. As is also shown in Fig. 10, the separate elements 30' may take the form of a plurality of narrow elongated metallic strands. In Fig. 10, a wire brush-like bundle of metallic strands is shown crimped to a conductor section 14' by bending a metal

finger 66 away from the conductor section 14' and crimping the finger 66 over the wires.

As shown in Fig. 11, other embodiments could include tangs 42" formed with terminations 68 that each include a pair of slots for receiving insulated electrical wires, i.e., "insulation displacement"-type terminations. When an insulated wire is forced laterally into one of these slots, metal edges defining the sides of the slot cut through and force apart the wire insulation to expose and make electrical contact with the wire.

In embodiments using insulation-displacement type tang terminations 68, wires extending from the armature windings 69 could be forced into the respective terminals 42" either during or after armature winding process. This would eliminate the need to weld or heat-stake the wires to the tang terminations 68.

As with the face-type commutator assembly 12 of Figs. 1-10, the barrel-type overmolded carbon segment commutator assembly 12c shown in Figs. 21-23 includes an annular array of twelve circumferentially spaced copper conductor sections 14c arranged around a rotational axis and an annular array of twelve circumferentially-spaced carbon segments 18c. However, unlike the face-type commutator assembly 12 the annular array of carbon segments 18c of the barrel-type commutator assembly 12c defines a segmented composite outer-circumferential or cylindrical commutating surface 22c rather than a flat, circular commutating surface.

Each carbon segment 18c is overmolded onto upper and lower surfaces 32c, 33 of a corresponding one of the conductor sections 14c forming an annular array of commutator sectors 168 as shown in Figs. 22-26. Each conductor section 14c is embedded in one of the carbon segments 18c and includes a conductor tang 42c that extends radially outward from that carbon segment. As best shown in Figs. 22 and 23 each conductor tang 42c is bent ninety degrees axially downward at the point where it protrudes from its respective carbon segment 18c and is then bent diagonally upward and outward.

As shown in Fig. 26 the annular array of commutator sectors 168 includes an axial top end surface 170, an axial base end surface 172 and an inner circumferential surface 76c. An overmolded insulator hub 24c is disposed on the axial top end, base end and inner circumferential surfaces 170, 172, 76c of the annular array of commutator sectors 168 to mechanically interlock the commutator sectors 168. As best shown in Figs. 23 and 28, the insulator hub 24c is generally spool shaped and includes an upper annular disk-shaped portion 174, a lower annular disk-shaped portion 176 and a shaft portion 178 that connects the two disk-shaped portions 174, 176 and occupies a cylindrical space defined by the inner circumferential surface 76c of the commutator sectors 168. A central axial armature shaft aperture 26c passes through the shaft portion 178 of the insulator hub 24c and is disposed concentrically within the inner circumferential surface 76c of the commutator sectors 168.

As shown in Figs. 23, 25, 26 and 28, a generally circular coaxial retention groove 180 is disposed in the top end surface 170 of the annular array of commutator sectors 168 opposite the base end surface 172. A ring-shaped protrusion extends axially and concentrically downward from the upper disk-shaped portion 174 of the insulator hub and occupies the retention groove 180.

In practice, the face-type and barrel-type carbon commutator assemblies 12, 12c described above are each constructed by first forming the annular array of conductor sections 14, 14c. This is done by stamping the annular array from a single copper blank 70, 70c as shown in Figs. 4, 5 for use in the face-type commutator assembly 12 and Figs. 24, 25 and 27 for use in the barrel-type commutator assembly 12c. In each case, the stamping process leaves each conductor section 14, 14c connected by a thin, radially extending metal strip 72, 72c to an unstamped outer periphery 74, 74c of the copper blank 70, 70c. The thin copper strips 72, 72c allow the outer periphery 74, 74c to act as a support ring that holds the conductor sections 14, 14c in position, following stamping, for the subsequent steps in the commutator construction process.

The carbon overmold 20, 20c in then formed, as shown in Figs. 6 and 8 for the face-type commutator assembly 12 and in Figs. 25, 26 and 28 for the

barrel-type commutator assembly 12c, by molding the carbon composition onto an upper surface 32, 32c of the annular conductor section 14, 14c array. The carbon composition is overmolded in such a fashion as to completely cover and mechanically interlock the conductor sections 14, 14c. In constructing the barrel-type commutator assembly 12c the carbon composition is also molded to an underside surface 33 of the conductor section 14c array. This effectively embeds the conductor sections 14c in the carbon overmold 20c.

In the carbon overmolding process, the carbon composition flows into each conductor section aperture 34, 34c and over each peripheral edge of each conductor section. However, in constructing the face-type commutator assembly and as is best shown in Figs. 4, 6 and 8, the apex tab 40 of each conductor section 14 is left exposed by the carbon overmold 20. The apex tabs 40 extend radially inward into the armature aperture 26.

In constructing the face-type commutator assembly 12, the carbon composition also envelops the integral upturned conductor projections 30. This allows the projections 30 to extend through the thickness of an insulating surface skin that characteristically forms on exterior surfaces of a carbon overmold 20 as the carbon composition cures. By extending through the insulating skin, the projections 30 serve to reduce the electrical resistance of the contact by increasing the amount of surface area contact between carbon and copper.

In the carbon overmolding process for both the face-type and the barrel-type commutator assemblies 12, 12c the radial groove portions 54, 54c of the interstices 52, 52c are molded into an inside surface 76, 76c of the carbon overmold 20, 20c opposite the commutating surface 22, 22c and between the conductor sections 14, 14c. In the case of the face-type commutator assembly 12 the inside surface 76 is the flat base surface of the carbon overmold 20 that lies axially opposite the flat commutating surface 22. In the case of the barrel-type commutator assembly 12c, the inside surface 76c is the inner circumferential surface that lies radially opposite the outer circumferential commutating surface 22c. In each case, the grooves 54, 54c may, alternatively, be formed by other well-known means such as machining.

As shown in Figs. 1-3 and 27 and 28, the hub 24, 24c is then formed by a second overmolding operation that covers the carbon overmold 20, 20c and conductor section 14, 14c array with the hub insulator material. During this hub overmolding process, the hub insulator material surrounds a portion of the carbon overmold 20, 20c and the conductor sections 14, 14c. The hub insulator material also completely fills the radial grooves 54, 54c that were formed in the inside surface 76, 76c of the carbon overmold 20, 20c in the carbon overmolding process, i.e., the inner groove portions 54, 54c of the interstices 52 52c. Only the commutating surface 22, 22c portion of the carbon overmold 20, 20c is left exposed after the hub overmolding operation is complete.

In the case of the face-type commutator assembly 12, as the insulator hub 24 is being overmolded, insulator material that is formed around the circumference of the carbon segment 18 array also flows over the outer shelf-detent 50 of each carbon segment 18 as is best shown in Fig. 2. Insulator material that is formed around the armature shaft aperture 26 flows over the inner shelf-detent 48 of each carbon segment 18. After the hub insulator material has hardened over the inner 48 and outer 50 shelf-detents of each carbon segment 18 and after the insulator has hardened under the carbon segments 18 and conductor sections 14, the hardened hub insulator material serves to mechanically retain the carbon segments 18 in relation to each other. In addition, the hardened hub insulator material secondarily retains the carbon segments 18 to their respective conductor sections 14.

In the case of the barrel-type commutator assembly 12c, as the insulator hub 24c is being overmolded, insulator material that is formed over the upper axial surface of the carbon overmold 20c also flows into the circular retention groove as is best shown in Fig. 28. After the hub insulator material has hardened in the retention groove and after the insulator has hardened, the hardened hub insulator material serves to mechanically retain the carbon segments 18, 18c in relation to each other in their annular array.

In constructing both the face-type and barrel-type commutator assemblies 12 12c, after the hub 24, 24c has been overmolded onto the carbon

overmold 20, 20c and conductor section array, a portion of the outer periphery 74, 74c of the unstamped copper blank 70 is trimmed away from around the overmolded insulator hub 24, 24c. Once the periphery 74, 74c has been cut away, each conductor strip 72, 72c is bent to form a short tang 42, 42c of each connecting strip 72, 72c that is left protruding radially outward from an outer circumferential surface of the hub 24, 24c. The tangs 42, 42c are thus positioned and configured for use in connecting each conductor section 14, 14c to an armature wire extending from an armature winding.

As is best shown in Figs. 1-3 and 21 and 23, the annular array of electrically-isolated carbon segments 18, 18c is then formed by machining the shallow radial slots 56, 56c inward from the exposed commutating surface 22, 22c of the carbon overmold 20, 20c to the underlying radial grooves 54, 54c. The slots 56, 56c can be formed by contact or non-contact machining techniques including, but not limited to, those using serrated tooth saws.

Because the radial slots 56, 56c are in direct overlying, i.e., axial or radial, alignment with the radial grooves 54, 54c, the radial slots 56, 56c can be cut completely through the carbon overmold 20, 20c and slightly into the insulator material that occupies the radial grooves 54, 54c. This ensures that the carbon overmold 20, 20c is cut through and the carbon segments 18, 18c completely separated and electrically isolated from each other. The insulator-filled radial grooves 54, 54c and the radial slots 56, 56c therefore meet within the commutator and form the interstices 52, 52c between the carbon segments 18, 18c as described above.

In the case of the face-type commutator assembly 12, the insulator-filled radial groove portion 54 of each interstice 52 constitutes approximately half of the axial depth of each interstice 52. In the case of the barrel-type commutator assembly 12c, the insulator-filled radial groove portion 54c of each interstice 52c constitutes approximately two-thirds of the radial depth o each interstice 52c. Consequently, in each case, to cut the remaining portion of each interstice 52 requires only a relatively shallow slot 56, 56c.

As is representatively shown in Fig. 9 for the face-type commutator assembly 12, the completed commutator assembly 12 is assembled to an armature assembly 80. The clamshell mold 67 is then positioned over the newly assembled commutator-armature assembly, generally indicated at 81 in Fig. 9. While positioning the clamshell mold 67 over the commutator-armature assembly 81, the sealing surface 65 of the clamshell mold 67 is made to seal around the circumferential land 64. Insulator material is then injected into the clamshell mold 67. Once the insulator material has cured, the clamshell mold 67 is removed. This final overmolding step is intended to protect copper armature windings 69 and other corrosion-prone elements from chemically reacting with ambient fluids such as gasoline.

A commutator manufacturing process accomplished according to the present invention involves no copper machining and, therefore, produces no copper shavings and chips that can lodge between carbon segments 18 18c. In addition, no copper is left exposed to react with ambient fluids such as gasoline.

Because a commutator assembly 12 constructed according to the present invention requires only shallow slots 56, 56c in its commutating surface 22, 22c to electrically isolate its carbon segments 18, 18c, the completed commutator assembly 12, 12c is stronger and better able to resist breakage. In the case of the face-type commutator assembly 12, as an alternative to a stronger commutator assembly, the hub 24 of the commutator assembly 12 may be designed to be axially shorter, allowing the commutator-armature assembly to either be designed axially shorter or to carry more armature windings 69. In other words, designers can capitalize on the shorter hub length by either shortening the overall commutator-armature assembly or including more armature windings 69.

One other advantage of the shallow slots 56 in the face-type commutator assembly 12 is that they allow for the circumferential land 64 between the tangs 42 and the slots 56. By providing a convenient sealing surface for a clam shell mold, the circumferential land 64 eliminates the need for a more complicated operation that involves masking the slots 56 to prevent the outflow of overmolding material into and through the slots 56.

A first embodiment of a soldered (rather than carbon overmolded) barrel-style carbon segment commutator assembly construction for an electric motor is generally indicated at 100 in Figs. 12 -14. A second embodiment of the soldered barrel-style commutator assembly is generally indicated at 100' in Fig. 20. Reference numerals with the designation prime (') in Fig. 20 indicate alternative configurations of elements that also appear in the first embodiment. Unless indicated otherwise, where a portion of the following description uses a reference numeral to refer to the figures, we intend that portion of the description to apply equally to elements designated by primed numerals in Fig. 20.

The first embodiment of the barrel-type carbon-segment commutator assembly 100 comprises a generally circular annular array of twelve circumferentially spaced copper substrate sections generally indicated at 102 in Figs. 12-14. The substrate sections 102 are arranged around a rotational axis shown at 104 in Figs. 13 and 14. A cylindrical annular array of twelve circumferentially spaced carbon segments, shown at 106 in Figs. 12 and 13, is formed of a conductive carbon composition. Each of the twelve carbon segments 106 is connected to a corresponding one of the twelve metallic substrate sections 102 to form twelve commutator sectors 102, 106. A circular array of 12 radial interstices, shown at 108 in Figs. 12 and 14, physically separates and electrically isolates the composite commutator sectors 102, 106 from each other. A composite outer cylindrical surface of the annular carbon segment array defines a segmented cylindrical commutating surface, shown at 110 in Fig. 12, for making physical and electrical contact with a brush (not shown).

An insulator hub, generally indicated at 112 in Figs. 12-14, is disposed within the annular carbon segment array and mechanically interlocks the carbon segments 106. As is best shown in Figs. 13 and 14, the carbon segments 106 are electrically isolated from each other by the radial cuts 108 and are mechanically interconnected by the insulator hub 112.

As shown in Fig. 15, nickel and copper layers 114, 116 are plated onto an inner, i.e., the base end surface 118 of each carbon segment 106 with the copper layer 114 being plated over the nickel layer 116. The copper substrate

sections 102 are soldered to the respective plated base end surfaces 118 of the carbon segments 106 to provide strong mechanical and electrical connections between the carbon segments 106 and their respective substrate sections 102.

As is best shown in Fig. 14, each copper substrate section 102 has a flat, tapered, generally trapezoidal main body 120 with an arcuate outer edge 122. As shown in Figs. 12-14, a U-shaped terminal 124 extends radially and integrally outward from the arcuate outer edge 122 of each main body 120. A tang, best shown at 126 in Fig. 13, extends diagonally downward and outward from the main body 120 of each copper substrate section 102. Each tang 126 is embedded in the hub 112 to increase the strength of the mechanical lock between the substrate sections 102 and the hub 112.

As is explained in greater detail below, the substrate sections 102 are cut from a single generally circular annular copper substrate 128 that has been stamped and formed from a copper sheet. Each U-shaped terminal 124 is shaped to facilitate the attachment of coil wires (not shown) by soldering, the application of electrically conductive adhesive and/or physically wrapping such coil wires around the terminals 124.

The composition of the carbon segments 106 includes one or more materials selected from the group consisting of isostatic electrographite, carbon graphite, and fine-grained extruded graphite. The isostatic electrographite has the best properties but is also the most expensive. The carbon graphite is the cheapest of the three.

Each carbon segment 106 has a horizontal cross sectional shape that is generally trapezoidal and generally matches the shape of each main body portion 120 of the copper substrate sections 102. The carbon segments 106 each have a retention groove, shown at 130 in Fig. 13, formed into a top end 132 of each carbon segment 106 opposite the base end surface 118.

The nickel and copper layers 114, 116 completely and evenly coat the base end surface 118 of each carbon segment 106. As is described in greater detail below, a selective electroplating method is used to plate the nickel and copper layers 114, 116 onto the base end surfaces 118 of the carbon segments 106. This

method deposits nickel ions deep within pores (not shown) in the base end surfaces 114 of the carbon segments 106. The pores in the base end surfaces 114 are characteristic of the carbon compositions used to form the carbon segments 106.

A layer of solder, shown at 132 in Fig. 15, that bonds and is disposed between the copper substrate sections 102 and the carbon segments 106 contains flux. The flux is mixed into the solder paste used in the soldering process to insure even flux distribution and improved mechanical and electrical contact between the carbon segments 106 and the copper substrate sections 102.

The hub 112 comprises a phenolic compound such as Rogers 660 and is overmolded into a unitary shape that includes an annular shaft portion shown at 134 in Figs. 12-14. The annular shaft portion 134 extends between an annular cap portion shown at 136 in Figs. 12 and 13 and an annular base portion shown at 138 in Figs. 12-14. The shaft 134, cap 136 and base 138 are coaxially aligned and have a common inner circumferential surface forming a constant-diameter tube 140 sized to fit over an armature shaft (not shown) in an electric motor.

The cap portion 136 of the hub 112 extends radially outward from the shaft portion 134 into an annular shape that covers a majority of the upper ends 132 of the carbons segments 106. The cap portion 136 of the hub 112 also occupies the carbon segment retention grooves 130 - mechanically locking the carbon segments 106 together.

Similar to the cap portion 136 of the hub 112, the hub base 138 extends radially outward from the shaft portion 134 into an annular shape that encases all but the U-shaped contact portions 124 of the copper substrate sections 102.

A soldered face-type carbon segment commutator assembly construction for an electric motor is generally indicated at 200 in Figs. 29 and 30. The face-type commutator assembly 200 comprises a generally circular annular array of eight circumferentially spaced copper substrate sections generally indicated at 202 in Figs. 29 and 30. The substrate sections 202 are arranged around a rotational axis shown at 204 in Figs. 29 and 30. A cylindrical annular array of eight circumferentially-spaced carbon segments, shown at 206 in Figs. 29 and 30, is

formed of a suitable conductive carbon composition such as those described above with reference to the barrel-type carbon commutator assembly 100. Each of the eight carbon segments 206 is connected to a corresponding one of the eight metallic substrate sections 202 to form eight commutator sectors 202, 206. A circular array of eight radial interstices, shown at 208 in Figs. 29 and 30, physically separate and electrically isolate the composite commutator sectors 202, 206 from each other. A composite circular surface formed by the annular carbon segment array defines a segmented cylindrical commutating surface, shown at 210 in Figs. 29 and 30, for making physical and electrical contact with a brush (not shown).

An insulator hub, generally indicated at 212 in Figs. 29 and 30, is disposed beneath the annular carbon segment array and mechanically interlocks the carbon segments 206. The carbon segments 206 are electrically isolated from each other by the radial cuts 208 and are mechanically interconnected by the insulator hub 212.

As shown in Fig. 15, nickel and copper layers 214, 216 are plated onto an inner, i.e., the base end surface 218 of each carbon segment 206 with the copper layer 214 being plated over the nickel layer 216. The copper substrate sections 202 are soldered to the respective plated base end surfaces 218 of the carbon segments 206 to provide strong mechanical and electrical connections between the carbon segments 206 and their respective substrate sections 202.

Each copper substrate section 202 is configured similar to the substrate sections 102 of the barrel-type commutator assembly 100 shown in Fig. 14 and described above. Each substrate section 202 includes a main body portion 220, a terminal 224 and a tang 226.

Each carbon segment 206 has a horizontal cross sectional shape that is generally trapezoidal and generally matches the shape of each main body portion 220 of the copper substrate sections 202.

The nickel and copper layers 214, 216 completely and evenly coat the base end surface 218 of each carbon segment 206. As mentioned above with respect to the barrel-type commutator 100 and as is described in greater detail

below, a selective electroplating method is used to plate the nickel and copper layers 214, 216 onto the base end surfaces 118 of the carbon segments 106.

A layer of solder containing flux, shown at 232 in Fig. 15, bonds and is disposed between the copper substrate sections 102 and the carbon segments 106. The flux is mixed into the solder paste used in the soldering process to insure even flux distribution and improved mechanical and electrical contact between the carbon segments 106 and the copper substrate sections 102.

As with the barrel-type commutator 100, the hub 212 of the face-type commutator assembly 200 comprises a phenolic compound such as Rogers 660 and is molded into a unitary shape that includes an annular shaft portion shown at 234 in Fig. 30. The annular shaft portion 234 extends integrally and axially downward from an annular base portion shown at 238 in Fig. 30. The shaft 234 and base 238 are coaxially aligned and have a common inner circumferential surface forming a constant-diameter tube 240 sized to fit over an armature shaft (not shown) in an electric motor.

The hub base 238 extends radially outward from the shaft portion 234 into an annular shape that encases all but the U-shaped contact portions 124 of the copper substrate sections 102.

In practice, a soldered barrel-style or face-type carbon commutator assembly 100, 200 may be constructed according to the invention by first stamping the above-described copper substrate 128, 228 from a copper sheet as shown in Figs. 16 and 17 for a barrel commutator assembly 100. A carbon cylinder 142, 242 is then either machined or molded from a conductive carbon composition as shown in Fig. 18 for a barrel commutator assembly 100.

In constructing a barrel commutator assembly 100, a circular retention groove 144 is molded or machined into an outer or top end 146 of the carbon cylinder 142. The groove is concentric with the inner and outer diameters of the cylinder 142 and is disposed approximately midway between them.

In constructing either a barrel or face-type commutator assembly 100, 200, an inner, i.e., a base end 148, 248 of the carbon cylinder 142, 242 is metallized by electroplating a layer of nickel, shown at 114, 214 in Fig. 15, and a

layer of copper, shown at 116, 216 in Fig. 15, to the base end surface 148, 248 of the carbon cylinder 142, 242. The metallic substrate 128, 228 is then soldered to the metallized base end 148, 248 of the carbon cylinder 142, 242.

In constructing the barrel commutator 100, the hub 112 is then formed within the carbon cylinder 142. In constructing the face commutator 200 the hub 212 may be formed to an underside surface of the metallic substrate 228 either before or after soldering the substrate 228 to the metallized base end surface 248 of the carbon cylinder 242.

For the barrel commutator assembly 100 the interstices 108 are then machined radially inward through the carbon cylinder 142 and the metallic substrate 128 to form the electrically isolated carbon/metal commutator sectors 102, 106. The over-molded hub 112 physically holds the commutator sectors 102, 106 together after the interstices 108 are formed.

For the face commutator assembly 200 the interstices 208 are machined axially inward through the carbon cylinder 242 and the metallic substrate 228 to form the electrically isolated carbon/metal commutator sectors 202, 206. The hub 212 physically holds the commutator sectors 202, 206 together after the interstices 208 are formed.

For both the barrel and face commutator assemblies 100, 200 a stencil printing process is used to apply solder, shown at 132, 232 in Fig. 15, to the base end surface 148, 248 of the carbon cylinder 142, 242. According to this process, the carbon cylinder 142, 242 is placed in a tray fixture of a stencil-printing machine (not shown). The stencil-printing machine is then cycled to place a stencil (not shown) over the base end surface 148, 248 of the carbon cylinder 142, 242. The stencil masks a center hole defined by the annular shape of the base end surface 148, 248. The machine then spreads a layer of solder paste over the stencil and exposed portions of the metallized carbon cylinder base end surface 148, 248 with a rubber squeegee. The machine then removes the stencil and excess solder paste from the carbon cylinder 142, 242. The stencil-printing machine used in this process is a De Hocurt Model EL-20.

After the stencil printing machine applies the solder paste, the substrate 128, 228 is concentrically aligned with the base end surface 148, 248 of the carbon cylinder 142, 242 and is placed flat against the solder-coated base end surface 148, 248 of carbon cylinder 142. The assembly 100 is then placed in a reflow oven (not shown) to insure that the solder 132, 232 has properly bonded the cylinder and substrate surfaces 142, 242, 128, 228.

As mentioned above, the nickel and copper layers 114, 214, 116, 216 are applied by electrolysis. More specifically, a brush-type selective plating process is used to electroplate the nickel and copper onto the carbon cylinder base end surface 118, 218. Brush-type selective plating includes the use of an electrolytic ion solution dispenser in the form of a hand held wand with an absorbent brush applicator at one end. An anode generally composed of the metal to be electroplated is selectively retained within a cavity formed in the wand. The carbon cylinder 142, 242 is charged as a cathode. This process results in a very high electrolytic current density that "throws" metal ions deep into the pores of the carbon cylinder cathode 142, 242 when the applicator is saturated with the ion solution and is drawn across the base end surface 148, 248 of the cylinder 142, 242. This results in excellent mechanical and electrical contact. A suitable brush-type selective plating process is disclosed in detail in United States Patent Number 5,409,593. This patent is assigned to Sifco Industries, Inc. and is incorporated herein by reference.

An alternative process for metallizing the base end surface 148, 248 of the carbon cylinder 142, 242 includes forming the thin tin-based chemical reaction zone at the inner or base end surface 148, 248 of the carbon cylinder 142, 242 by first providing a metallic powder mixture of tin with particular transition metals (typically Cr) added to typically approximately 5 wt.% in an appropriate organic vehicle or binder to form a metalization paste that is painted or screen printed onto the base end surface 148, 248. The paste is then dried and fired generally to 800-900°C for roughly 10-15 minutes. Carbon monoxide gas (CO) is included in the firing atmosphere to facilitate a bonding/wetting reaction. Firing the paste in a nitrogen atmosphere generates sufficient CO locally due to binder

burnout. This procedure yields a direct metallurgical bond of the tin-rich composition to the base end surface 148, 248 forming the tin-based chemical reaction zone. The metallized surface can be safely reflowed at 232°C (the melting point of tin) without dewetting from the base end surface 148, 248. Through reflowing conventional solder compositions into the metallization layer, the base end surface 148, 248 can be converted into a solder layer, shown at 250 in Fig. 31, that is tenaciously adherent onto the base end surface 148, 248. A suitable metallization process that includes the above steps is available from Oryx Technology Corporation under the trade name Intragene™.

To form the hub 112 for the barrel-type commutator assembly 100, an insert molding process is used to mold phenolic compound over, under and within the annular carbon cylinder 142 and metallic substrate 128. In the process, the phenolic compound flows into and fills the retention groove 144.

For both the barrel and the face-type commutator assemblies, 100, 200 the individual copper substrate sections 102, 202 are formed by stamping the circular annular copper substrate 128, 228 from a copper sheet. As described above, each of the copper substrate sections 102, 202 includes a generally trapezoidal main body portion shown at 120 in Fig. 16 for the barrel commutator assembly 100. A terminal 124, 224 extends radially outward and a tang 126, 226 extends diagonally downward and radially outward from the main body portion of each substrate section 102, 202. The terminals 124, 224 and the tangs 126, 226 are best shown in Fig. 13 for the barrel-type commutator assembly and Fig. 30 for the face-type commutator assembly 200.

Before they are cut from the substrate 128, 228 the copper substrate main body portions 120 are partially separated from each other by radially outwardly extending slots shown at 150 in Fig. 16 for the barrel-type commutator assembly. The slots 150 extend radially outward from an inside diameter 152 of the annular copper substrate 128, 228. The substrate sections 102, 202 are connected by circumferentially extending connector tabs, shown at 154 in Fig. 16, that bridge radial outer ends of the outwardly extending slots 150.

After the circular annular copper substrate 128, 228 is stamped from a copper sheet, the tangs 126, 226 are formed by bending a radially inner tip 156 of each main body portion 120, 220 downward and radially outward from its original position in plane with the rest of the main body portion 120, 220. In addition, each terminal 124, 224 is formed into its upright U-shape by bending.

In constructing the barrel-type commutator assembly 100 the radial interstices shown at 108 in Figs. 12 and 14 are machined radially inward from the outer circumferential surface 110 of the carbon cylinder 142 through the shaft portion 134 of the hub 112. As the radial interstices 108 are machined, the circumferentially-extending substrate section connector tabs 154 are cut through to the outwardly extending radial slots 150, separating and electrically isolating the metallic substrate sections 102.

According to the second embodiment of the soldered barrel-style commutator, an inner groove portion 158 of each radial interstice is either machined or molded radially outward into an inner circumferential surface 160' of the carbon cylinder 142'. As shown in Fig. 20, the base end surface 148' of the carbon cylinder is then electroplated and is coated with solder paste in the stencil-printing machine. During stencil printing, the inner groove portions 158 are masked by the stencil that the stencil printing machine places over the metabolized base end surface 148' of the carbon cylinder 142' prior to solder paste application. The stencil prevents solder 132 from lodging in the inner groove portions 158.

Once the carbon cylinder 142' has been soldered to the substrate 128', the hub (not shown in Fig. 20) is overmolded. During overmolding, the phenolic compound is allowed to flow into and fill the inner groove portions 158. Outer slot portions of the interstices 108 are then machined radially inward from an outer circumferential surface 110' of the carbon cylinder 142' to the insulator-filled inner groove portions 158. The outer slot portions of the interstices 108 are machined to align with and join the insulator-filled inner groove portions 158 to complete the radial interstices 108. Therefore, each radial interstice 108 has an inner groove portion 158 filled with the insulating phenolic compound and an unfilled outer slot portion.

Other embodiments of the barrel-type commutator assembly 100 may include a number of poles other than twelve. Likewise, other embodiments of the face-type commutator assembly 200 may include a number of poles other than eight. In addition, conducting metals other than copper and nickel may be used to electroplate the inner, i.e., the base end surface 118 of the carbon segments 106. Other embodiments may also employ insulation displacement terminals similar to the terminal 14" shown in Fig. 11. In other embodiments, the hub 112 may comprise a suitable insulating composition other than a phenolic compound.

This is an illustrative description of the invention using words of description rather than of limitation. Obviously, many modifications and variations of this invention are possible in light of the above teachings. Within the scope of the claims, one may practice the invention other than as described.

We claim:

1. A carbon-segment commutator assembly for an electric motor, the commutator assembly comprising:

an annular array of at least two circumferentially spaced conductor sections arranged around a rotational axis;

an annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition, each carbon segment overmolded onto at least one surface of a corresponding one of the conductor sections, the annular array defining a segmented commutating surface of the commutator;

an overmolded insulator hub disposed around and between the carbon segments, the insulator hub mechanically interlocking the carbon segments and including an outer surface;

each conductor section having at least one conductor projection at least partially embedded in a corresponding one of the overmolded carbon segments to reduce electrical resistance by increasing surface area contact between each conductor section and its corresponding carbon segment.

2. A commutator assembly as defined in claim 1 in which the conductor projection comprises a plurality of narrow elongated metallic strands.

3. A commutator assembly as defined in claim 1 in which the conductor sections are made of copper.

4. A commutator assembly as defined in claim 1 in which the commutator assembly is a planar face-type commutator assembly.

5. A commutator assembly as defined in claim 4 in which each conductor section includes an outwardly extending tang portion and in which each conductor section is embedded between the insulator hub and the overmolded

carbon segment with the tang portion of each conductor section protruding outward from the insulator hub outer surface.

6. A commutator assembly as defined in claim 5 further including radial interstices separating the carbon segments, each interstice having an inner groove portion filled with the hub insulator material and an unfilled outer slot portion, and in which the insulator hub includes a circumferential land disposed between the tangs and the unfilled outer slot portion of the interstices.

7. A commutator assembly as defined in claim 1 in which the carbon segments comprise a composition of carbon powder and carrier material.

8. A commutator assembly as defined in claim 7 in which the carbon segments comprise metal particles embedded in the composition of carbon powder and carrier material.

9. A commutator assembly as defined in claim 7 in which the carrier material is selected from the group consisting of phenolic resin, a thermoset resin and a thermoplastic resin.

10. A commutator assembly as defined in claim 7 in which 50-80% of the weight of the carbon composition is made up of graphite.

11. A carbon-segment commutator assembly for an electric motor, the commutator assembly comprising:

an annular array of at least two circumferentially spaced conductor sections arranged around a rotational axis;

an annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition, each carbon segment overmolded onto at least one surface of a corresponding one of the conductor

sections, the annular array defining a segmented commutating surface of the commutator;

an overmolded insulator hub disposed around and between the carbon segments, the insulator hub mechanically interlocking the carbon segments and including an outer surface; and

metal particles embedded in the carbon composition to reduce electrical resistance between each conductor section and its corresponding carbon segment by improving carbon segment surface conductivity.

12. A commutator assembly as defined in claim 11 in which the carbon composition comprises carbon powder and carrier material.

13. A commutator assembly as defined in claim 11 in which each conductor section has at least one conductor projection at least partially embedded in a corresponding one of the overmolded carbon segments.

14. A carbon-segment commutator assembly for an electric motor, the commutator assembly comprising:

an annular array of at least two circumferentially spaced conductor sections arranged around a rotational axis;

an annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition, each carbon segment overmolded onto at least one surface of a corresponding one of the conductor sections forming an annular array of commutator sectors, the annular array of commutator sectors including an axial top end surface, an axial base end surface and an inner circumferential surface, the annular array of carbon segments defining a segmented composite outer-circumferential commutating surface of the commutator; and

an overmolded insulator hub disposed on the axial top end, base end and inner circumferential surfaces of the annular array of commutator sectors to mechanically interlock the commutator sectors, the insulator hub including a central

axial aperture disposed concentrically within the inner circumferential surface of the commutator sectors.

15. A commutator assembly as set forth in claim 14 in which:

a circular retention groove is disposed in the top end surface of the annular array of commutator sectors opposite the base end surface; and

a portion of the insulator hub is disposed within the retention groove.

16. A commutator assembly as set forth in claim 14 in which each conductor section is at least partially embedded in one of the carbon segments and includes a conductor tang that extends radially outward from that carbon segment.

17. A commutator assembly as defined in claim 14 further including radial interstices separating the carbon segments, each interstice having an inner groove portion filled with the hub insulator material and an unfilled outer slot portion.

18. A commutator assembly as defined in claim 14 in which the carbon segments comprise a composition of carbon powder and carrier material.

19. A commutator assembly as defined in claim 18 in which the carbon segments comprise metal particles embedded in the composition of carbon powder and carrier material.

20. A commutator assembly as defined in claim 18 in which the carrier material is selected from the group consisting of phenolic resin, a thermoset resin and a thermoplastic resin.

21. A commutator assembly as defined in claim 18 in which 50-80% of the weight of the carbon composition is made up of graphite.

22. A method for making a carbon commutator assembly comprising an annular array of at least two circumferentially-spaced conductor sections arranged around a rotational axis, an annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition, each carbon segment being formed onto at least one surface of a corresponding one of the conductor sections forming an annular array of commutator sectors, the annular array of commutator sectors forming a central axial aperture, the annular array of carbon segments defining a segmented composite commutating surface of the commutator, an overmolded insulator hub at least a portion of which is disposed within the central axial aperture, the insulator hub mechanically interlocking the carbon segments; the method comprising the steps of:

providing an annular array of conductor sections;

overmolding an electrical-conducting resin-bonded carbon composition onto the annular conductor section array for providing a carbon overmold thereon;

forming inner grooves in an inside surface of the carbon overmold opposite the commutating surface;

overmolding insulator material onto the carbon overmold and conductor section array for providing an insulator hub that at least partially occupies the inner grooves and mechanically interlocks the carbon segments; and

machining slots inward from the commutating surface of the carbon overmold to the inner grooves to form the annular array of electrically isolated carbon segments while electrically isolating the segments from each other.

23. A method as set forth in claim 22 in which the step of forming the inner grooves is included in the step of overmolding an electrical-conducting resin-bonded carbon composition.

24. A method as set forth in claim 22 in which:

the step of overmolding an electrical-conducting resin-bonded carbon composition includes the step of forming a retention groove in an axial top surface of the carbon overmold; and

the step of overmolding insulator material includes the step of flowing the insulator material over the top surface and into the retention groove.

25. A method as set forth in claim 22 in which the step of overmolding an electrical-conducting resin-bonded carbon composition includes the step of molding the carbon composition over and under the annular array of conductor sections.

26. A method as set forth in claim 22 in which the step of providing an annular array of conductor sections includes the step of stamping the annular array of conductor sections from a single copper blank.

27. A method as set forth in claim 26 in which the step of stamping the annular array of conductor sections includes the step of leaving each conductor section connected by a thin metal strip to an unstamped outer periphery of the copper blank.

28. A method as set forth in claim 27 further including the step of machining the slots shallow enough to leave a circumferential land disposed on an outer circumferential surface of the hub between the thin metal strips and the slots.

29. A method as set forth in claim 27 further including the additional step of trimming away at least a portion of the unstamped copper blank outer periphery from around the insulator hub following the step of overmolding the carbon overmold and conductor section array.

30. A method as set forth in claim 28 further including the steps of:

positioning a clam shell mold over the commutator assembly and a connected armature;

sealing one end of the clam shell mold around the circumferential land;

injecting insulator material into the clamshell mold;

allowing the injected insulator material to cure; and

removing the clam shell mold.

31. A carbon-segment commutator assembly for an electric motor, the commutator assembly comprising:

an annular array of at least two circumferentially spaced metallic substrate sections arranged around a rotational axis;

a cylindrical annular array of at least two circumferentially-spaced carbon segments formed of a conductive carbon composition, each segment connected to a corresponding one of the metallic substrate sections to form a commutator sector, a composite outer cylindrical surface of the annular carbon segment array defining a segmented cylindrical commutating surface;

an insulator hub disposed within the annular carbon segment array and mechanically interlocking the carbon segments; and

a first metallic layer plated onto a base end surface of each carbon segment, the metallic substrate sections soldered to the respective plated base end surfaces of the carbon segments to improve mechanical and electrical connections between the carbon segments and their respective substrate sections.

32. A commutator assembly as set forth in claim 31 in which a second metallic layer is plated over the first metallic layer.

33. A commutator assembly as set forth in claim 32 in which the first metallic layer comprises nickel and the second metallic layer comprises copper.

34. A commutator assembly as set forth in claim 31 in which small pores extend into the base end surface of each carbon segment and the metallic material of the first metallic layer is deposited within the pores in the base end surface of each carbon segment.

35. A commutator assembly as set forth in claim 31 in which:

the carbon segments each have a retention groove formed adjacent a top end of each respective carbon segment opposite the base end; and

the hub is formed into the retention groove.

36. A commutator assembly as set forth in claim 31 in which each substrate section includes a tang extending integrally outward into the hub, the tang being embedded in the hub.

37. A commutator assembly as set forth in claim 31 in which each carbon segment comprises a conductive carbon composition.

38. A commutator assembly as set forth in claim 37 in which each carbon segment comprises a composition of materials including at least one material selected from the group consisting of isostatic electrographite, carbon graphite, and fine-grained extruded graphite.

39. A commutator assembly as set forth in claim 31 in which the hub comprises a phenolic compound.

40. A commutator assembly as set forth in claim 31 further including a circular array of radial interstices separating the composite commutator sectors, each interstice having an inner groove portion filled with the hub insulator material and an unfilled outer slot portion.

41. A method for making a carbon commutator assembly comprising an annular array of circumferentially spaced metallic substrate sections arranged around a rotational axis, a cylindrical annular array of circumferentially-spaced carbon segments formed of a conductive carbon composition, each segment connected to a corresponding one of the metallic substrate sections to form an annular array of commutator sectors, a composite outer surface of the annular carbon segment array defining a segmented commutating surface, an annular insulator hub mechanically interlocking the commutator sectors, and a first metallic layer plated onto an inner surface of each carbon segment, the metallic substrate sections soldered to the respective plated inner surfaces of the carbon segments, the method including the steps of:

providing a metallic substrate;

providing an annular carbon cylinder of a conductive carbon composition, the cylinder having an inner surface and an outer commutating surface;

metallizing the inner surface of the carbon cylinder by bonding a first layer of metallic material to the inner surface of the carbon cylinder;

soldering the metallic substrate to the metallized inner surface of the carbon cylinder;

providing the insulator hub in a position supporting the metallic substrate and carbon cylinder; and

providing radial interstices through the carbon cylinder and the metallic substrate to form the electrically isolated carbon/metal commutator sectors.

42. A method as set forth in claim 41 in which the step of metallizing the inner surface includes the step of bonding a second layer of metallic material to the inner surface of the carbon cylinder

43. A method as set forth in claim 41 in which the step of metallizing the inner surface includes the step of electroplating a layer of metallic material to the inner surface of the carbon cylinder.

44. A method as set forth in claim 41 in which the step of metallizing the inner surface includes the step of using a brush-type selective electroplating process.

45. A method as set forth in claim 41 in which the step of metallizing the inner surface includes the step of providing a tin-based metallization layer including a chemical reaction zone at the inner surface of the carbon cylinder by:

forming a metallic powder mixture of tin with a transition metal;

forming a metallization paste by mixing the metallic powder mixture with an organic binder;

applying the metallization paste onto the base end surface;

firing the paste to 800-900°C in an atmosphere including carbon monoxide;

and in which the step of soldering includes the steps of:

converting the metallization layer into a solder layer by reflowing a solder composition into the metallization layer.

46. A method as set forth in claim 45 in which the step of forming a metallic powder mixture includes the step of providing Chromium as the transition metal.

47. A method as set forth in claim 46 in which the step of forming a metallic powder mixture includes the step of providing sufficient chromium to constitute approximately 5% of the mixture by weight.

48. A method as set forth in claim 45 in which the step of applying the metallization paste includes the step of screen printing the paste onto the base end surface.

49. A method as set forth in claim 45 in which the step of firing the paste includes the steps of:

firing the paste in a nitrogen atmosphere; and

generating carbon monoxide through binder burnout.

50. A method as set forth in claim 41 in which the step of soldering the substrate to the carbon cylinder includes the step of applying a solder paste to the inner surface, the solder paste containing flux.

51. A method as set forth in claim 41 in which the step of soldering the substrate to the carbon cylinder includes the step of using a stencil printing process to apply solder to the inner surface of the carbon cylinder, the stencil printing process including the steps of:

placing a stencil over the inner surface of the carbon cylinder;

providing a layer of solder on the stencil and exposed portions of the carbon cylinder inner surface; and

removing the stencil from the carbon cylinder.

52. A method as set forth in claim 41 in which the step of soldering the substrate to the carbon cylinder includes the step of placing the assembly in a reflow oven.

53. A method as set forth in claim 41 in which the step of providing a hub includes the step of overmolding insulator material onto the carbon cylinder and metallic substrate in an insert molding process to form the hub.

54. A method as set forth in claim 53 in which the overmolding step includes the step of flowing insulator material into a retention groove provided in the axial top end of the cylinder.

55. A method as set forth in claim 54 in which:

the method includes the additional step of forming an inner groove portion of each radial interstice radially outward into the carbon cylinder from an inner circumferential surface of the carbon cylinder prior to the step of providing a hub;

the overmolding step includes the step of flowing insulator material into the inner grooves; and

the step of providing radial interstices includes the step of machining outer slot portions of the interstices radially inward into the carbon cylinder from an outer circumferential surface of the carbon cylinder to the insulator-filled inner groove portions.

56. A method as set forth in claim 41 in which the step of providing a metallic substrate includes the step of stamping a generally circular annular metallic substrate from a sheet of metal.

57. A method as set forth in claim 56 in which the step of stamping includes the step of stamping a circular annular array of metallic substrate sections from the sheet of metal, each section including a main body portion, a terminal radially outwardly extending from each main body portion and a tang inwardly extending from each main body portion, the main body portions partially defined by radially inwardly extending slots, the substrate main body portions connected by connector tabs.

58. A method as set forth in claim 57 in which the step of stamping a circular annular array of metallic substrate sections includes the step of stamping an outwardly extending terminal having an insulation displacement configuration.

59. A method as set forth in claim 57 in which the step of providing radial interstices includes the step of machining through the connector tabs.

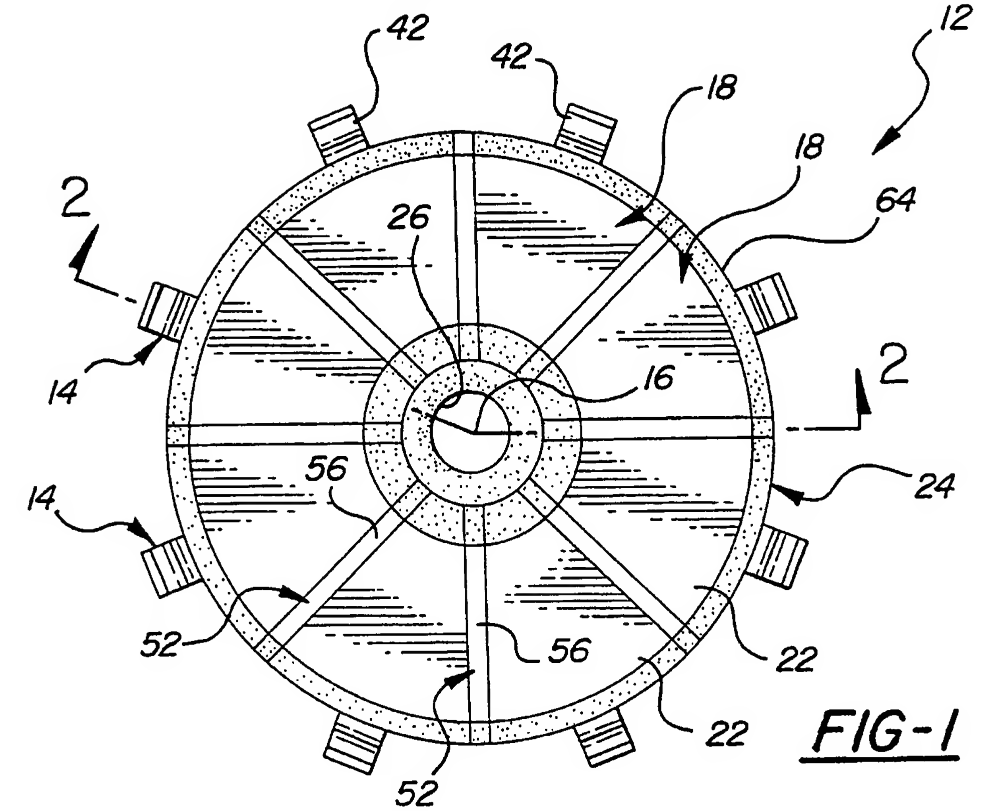


FIG-1

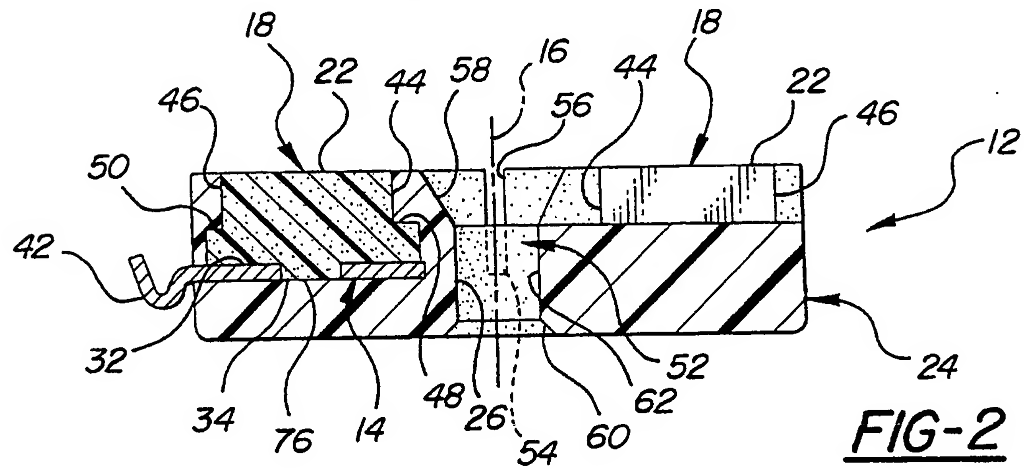


FIG-2

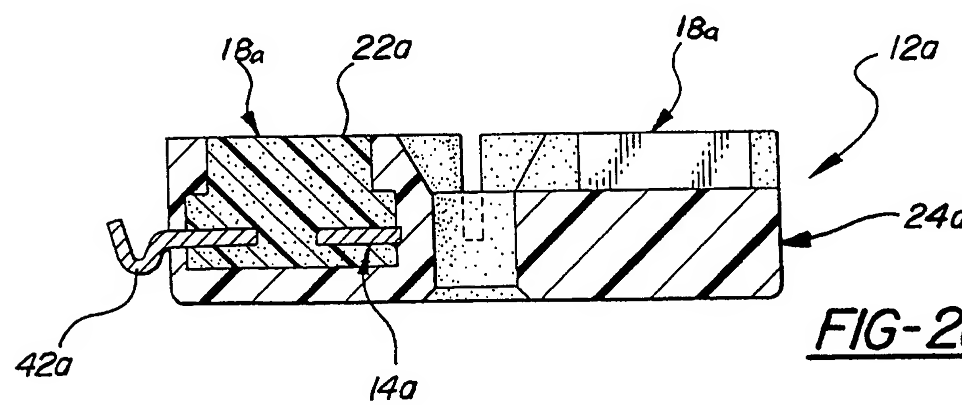


FIG-2a

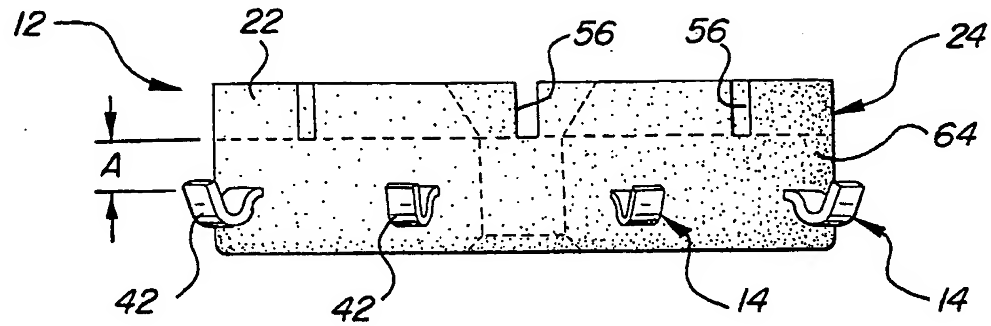


FIG-3

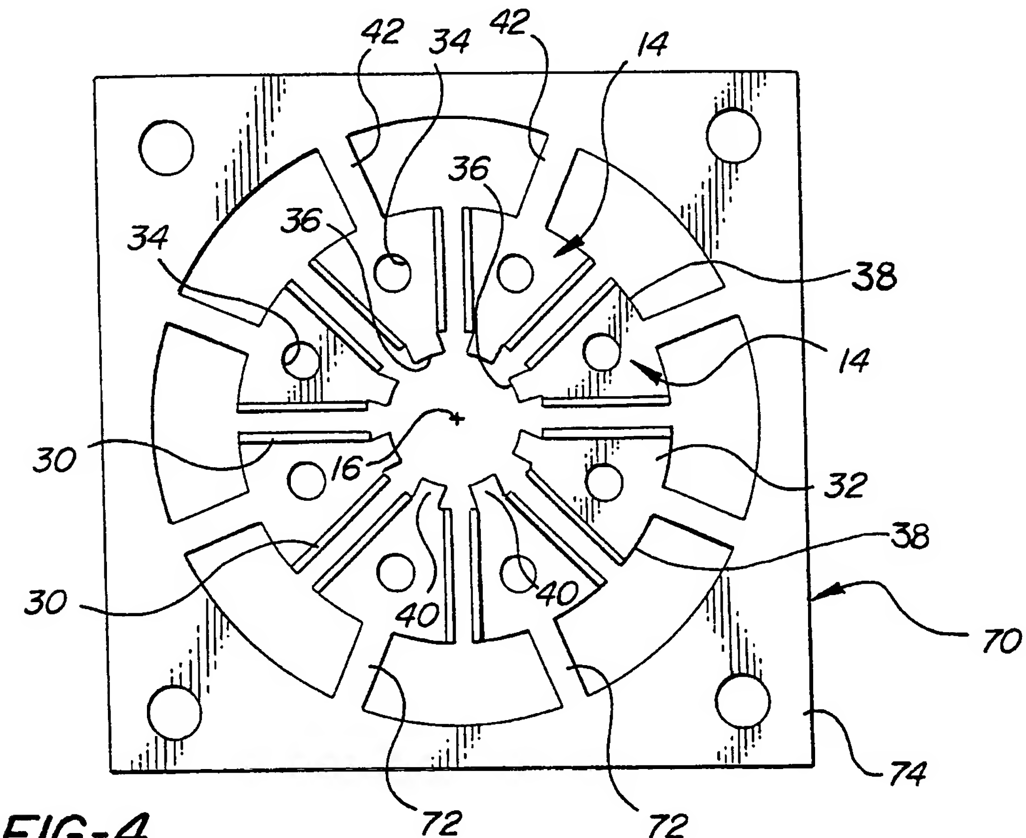


FIG-4

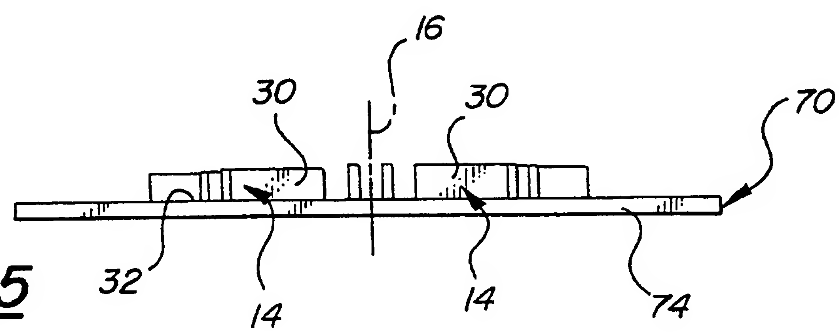


FIG-5

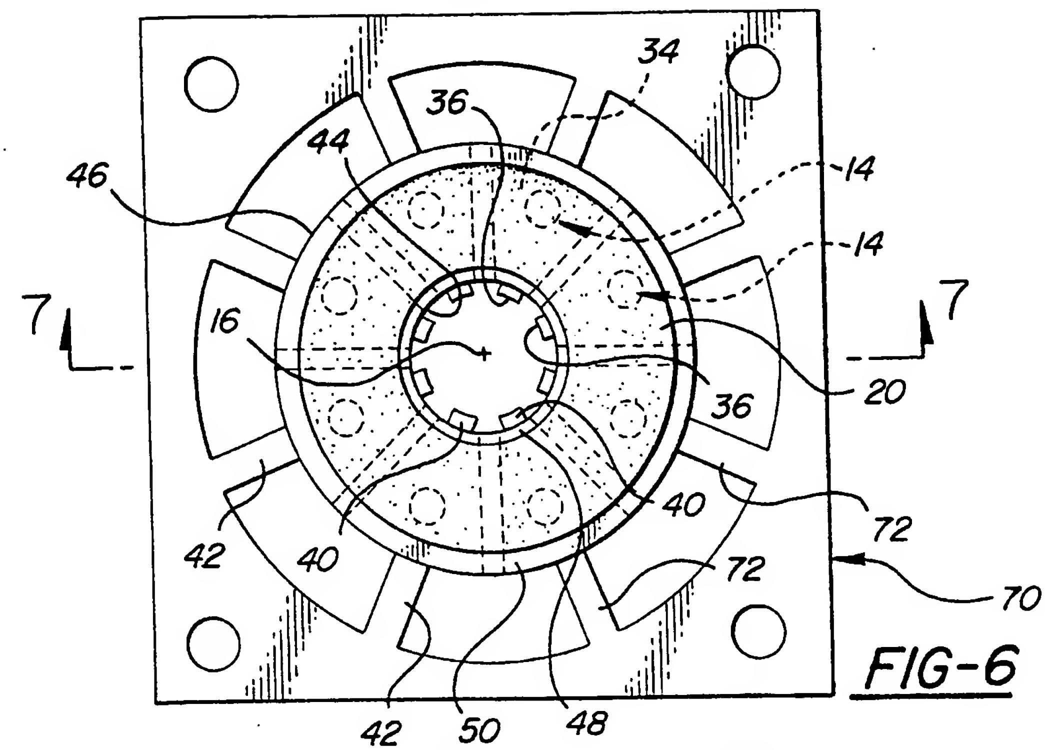


FIG-6

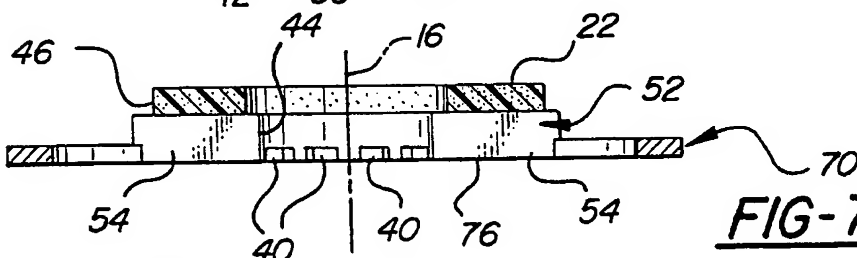


FIG-7

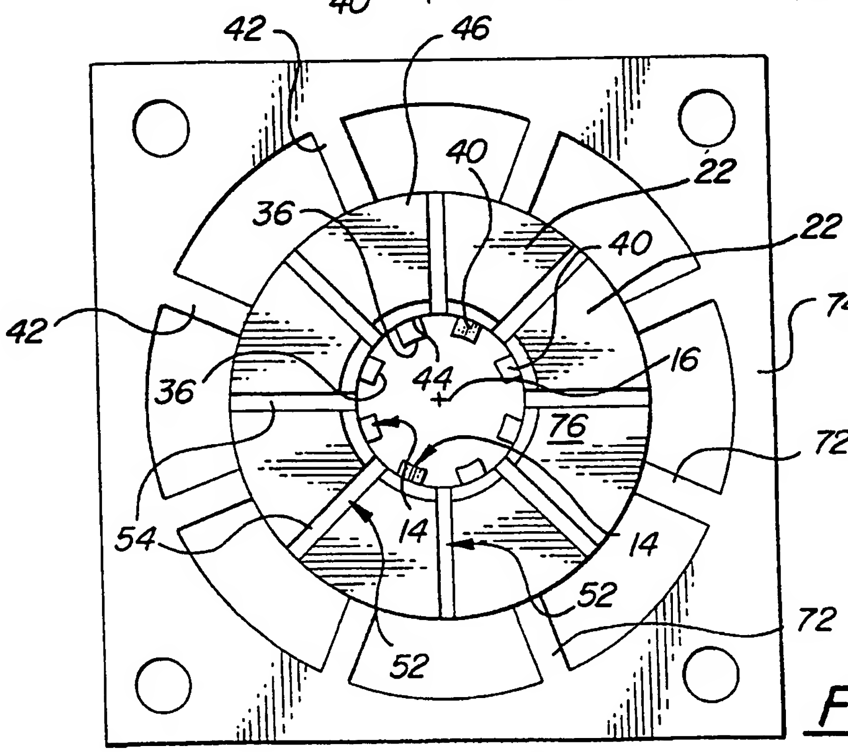


FIG-8

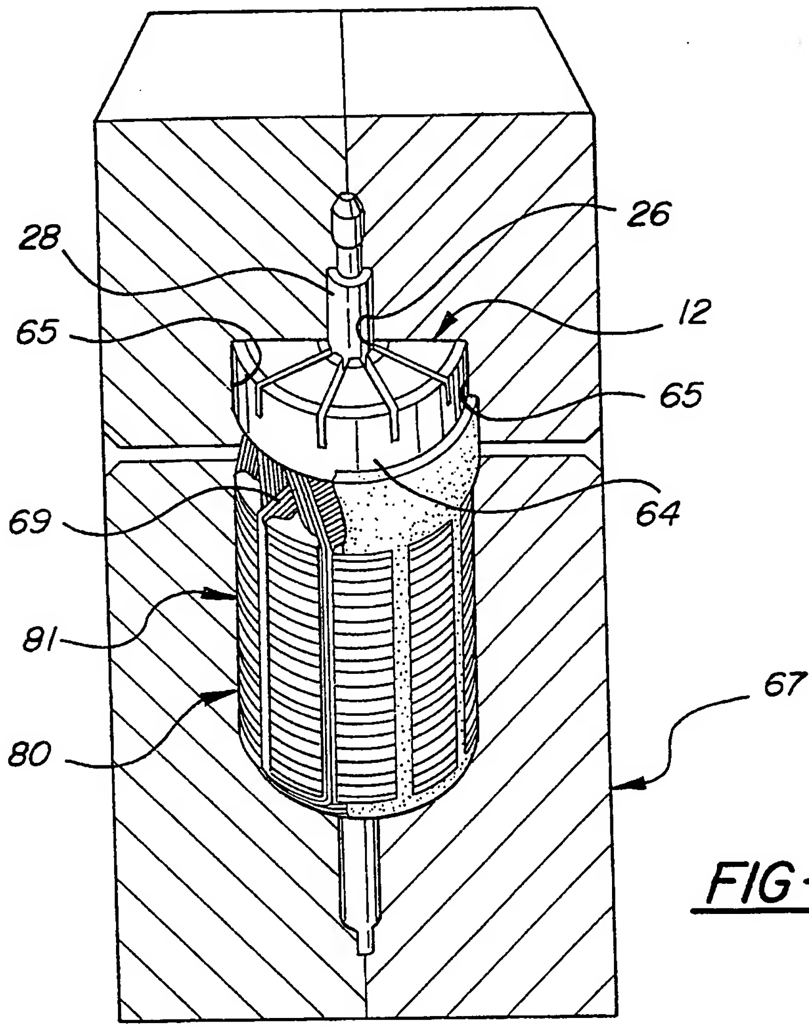


FIG-9

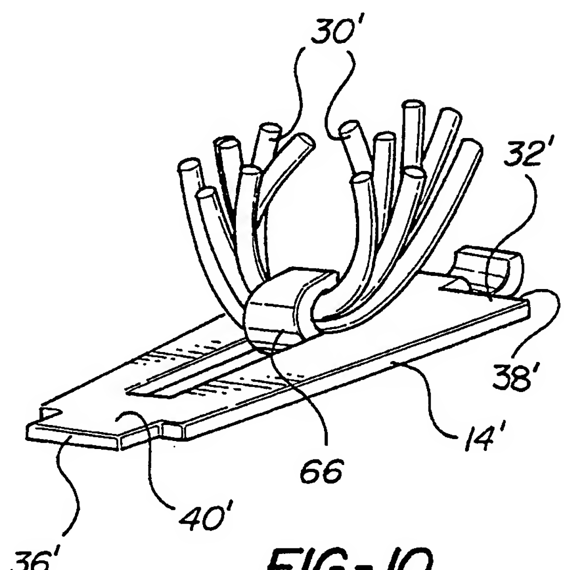


FIG-10

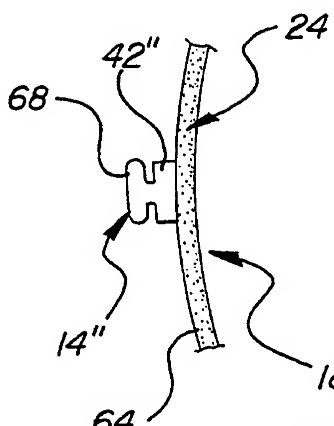


FIG-11

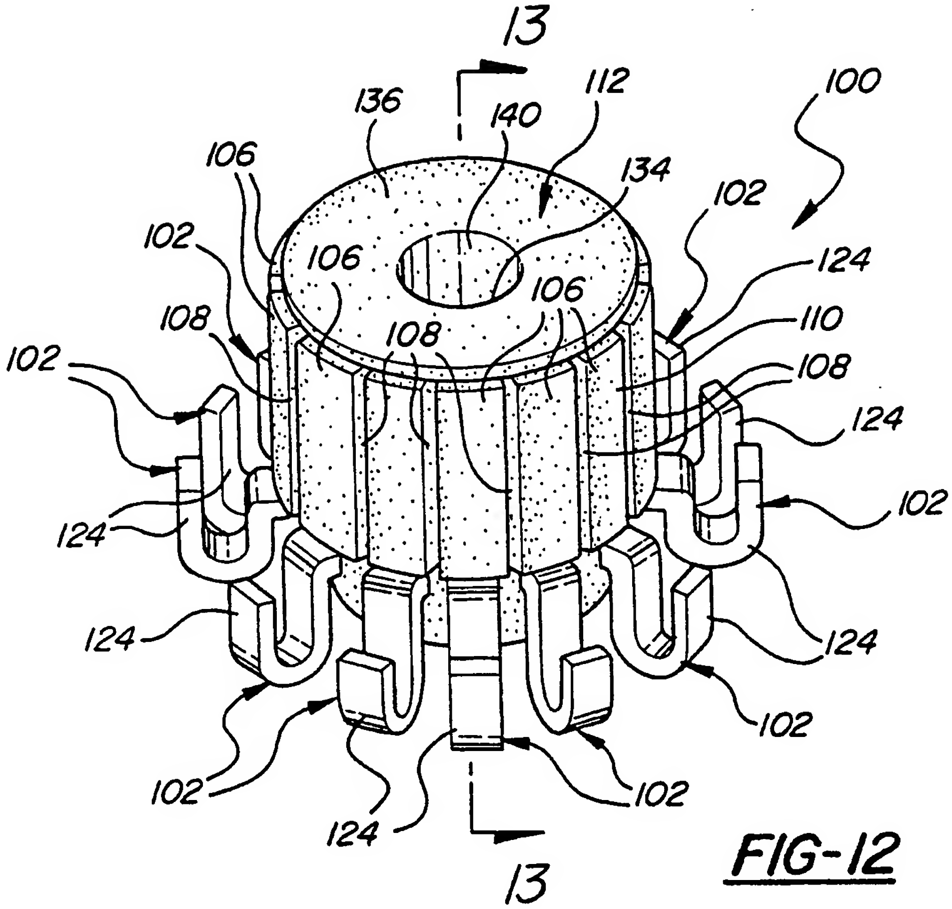
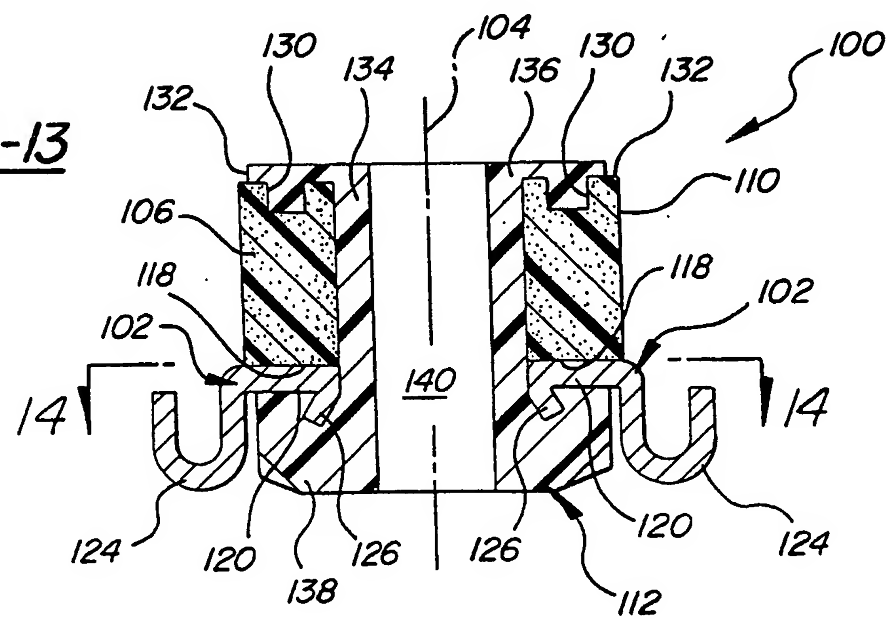

13
136
140
112
100
106
134
102
102
106
124
106
110
108
108
108
102
124
102
124
124
124
102
102
102
124
13

FIG-12

FIG-13


130
134
104
136
130
132
100
132
110
106
118
118
102
102
14
140
14
124
120
126
126
120
124
138
112

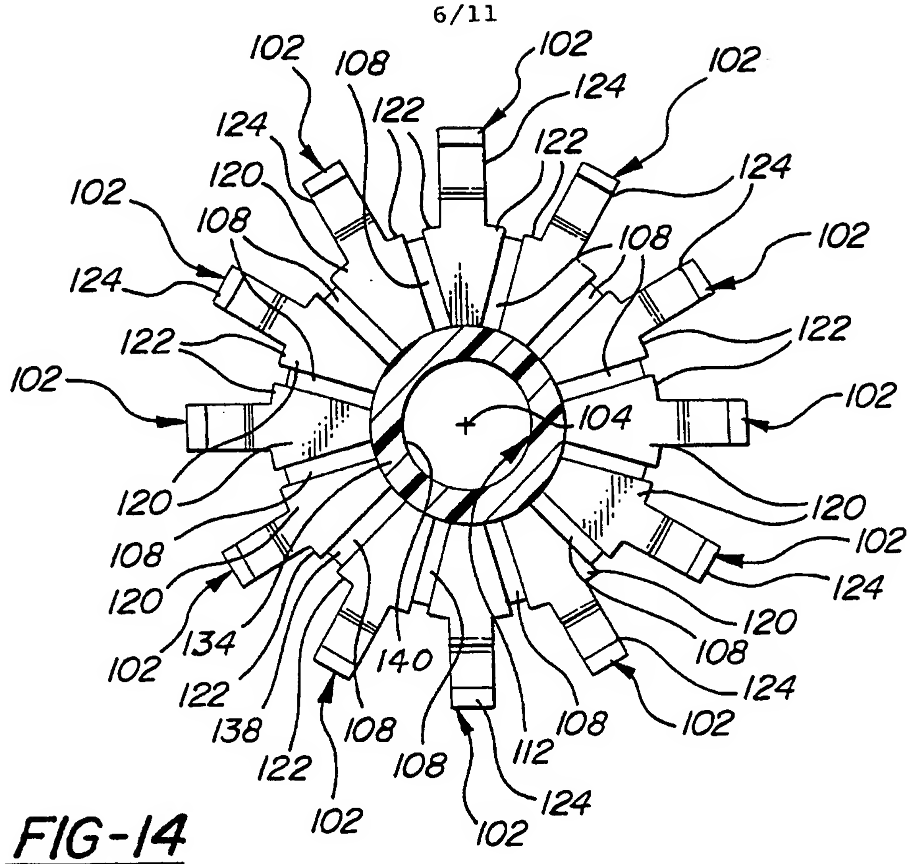
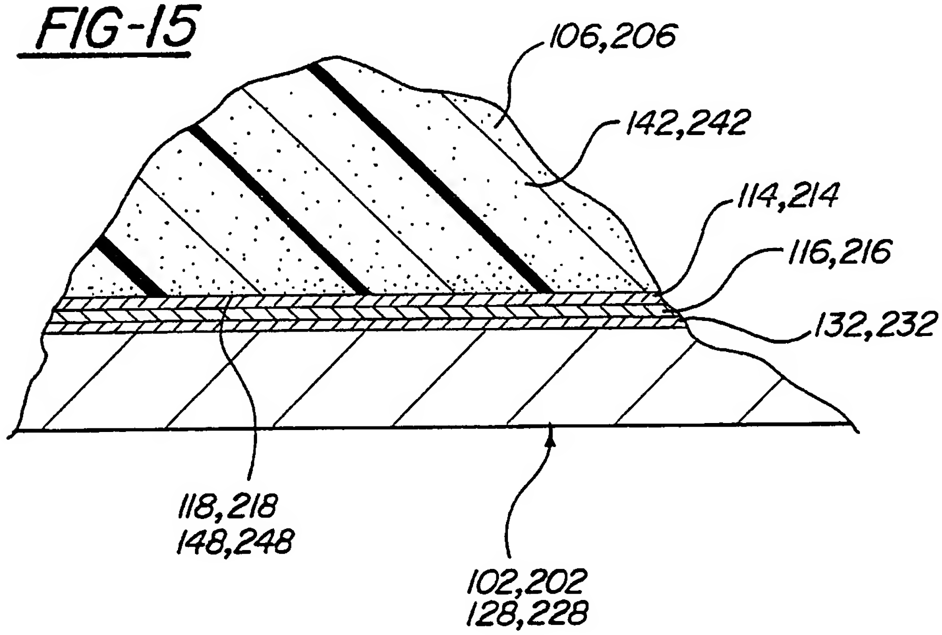

102
108
102
124
102
124
122
122
124
120
102
108
108
102
124
122
122
102
102
104
120
120
108
102
120
124
120
102
134
120
108
102
122
140
108
124
138
108
108
102
122
108
112
124
102
102

FIG-14

FIG-15


106,206
142,242
114,214
116,216
132,232
118,218
148,248
102,202
128,228

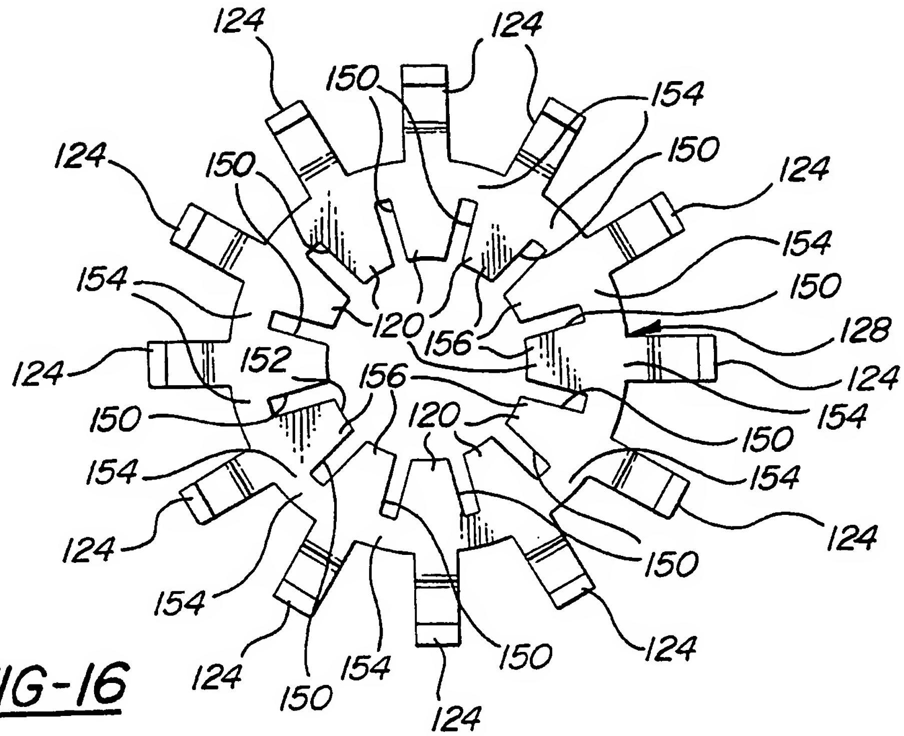


FIG-16

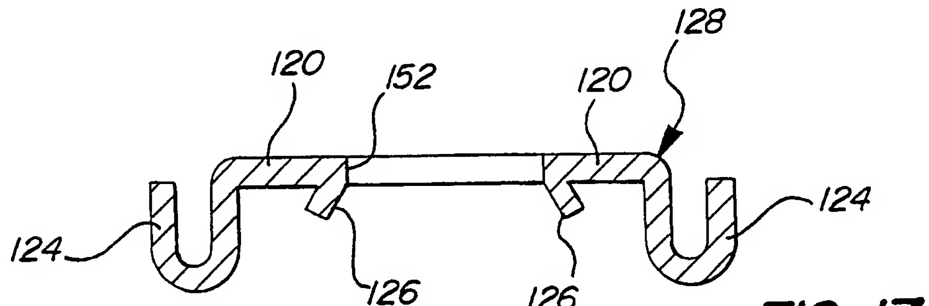
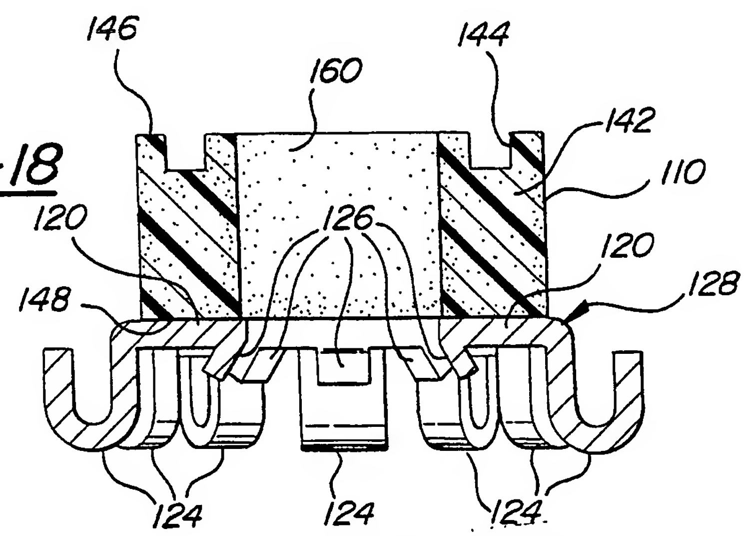


FIG-17

FIG-18



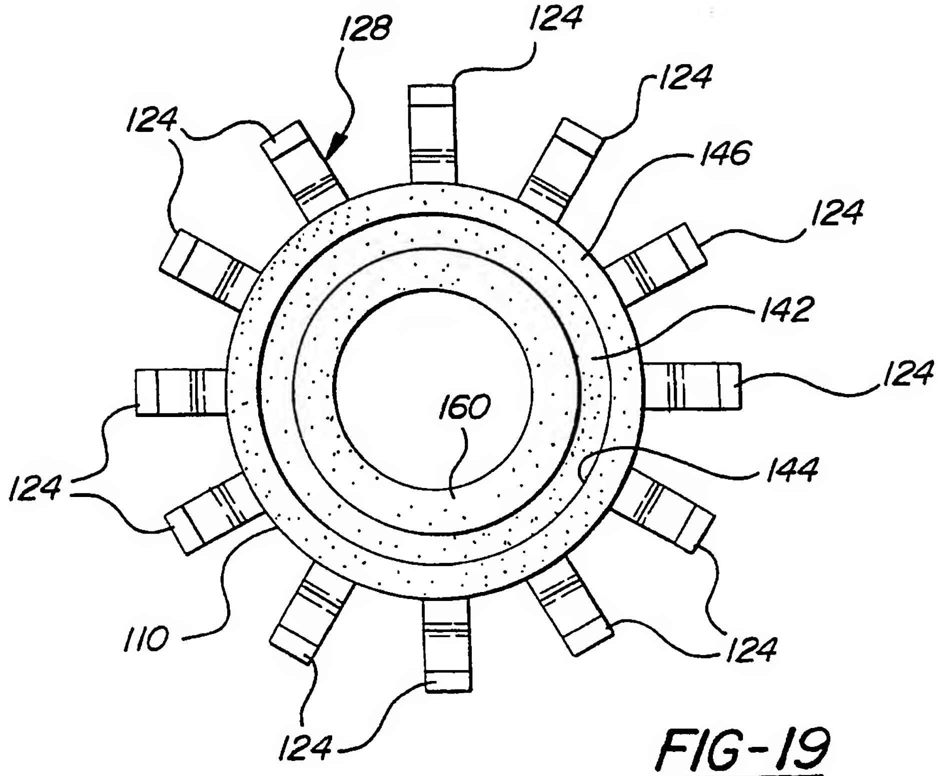

128
124
124
124
146
124
142
124
160
124
144
110
124
124

FIG-19

FIG-20

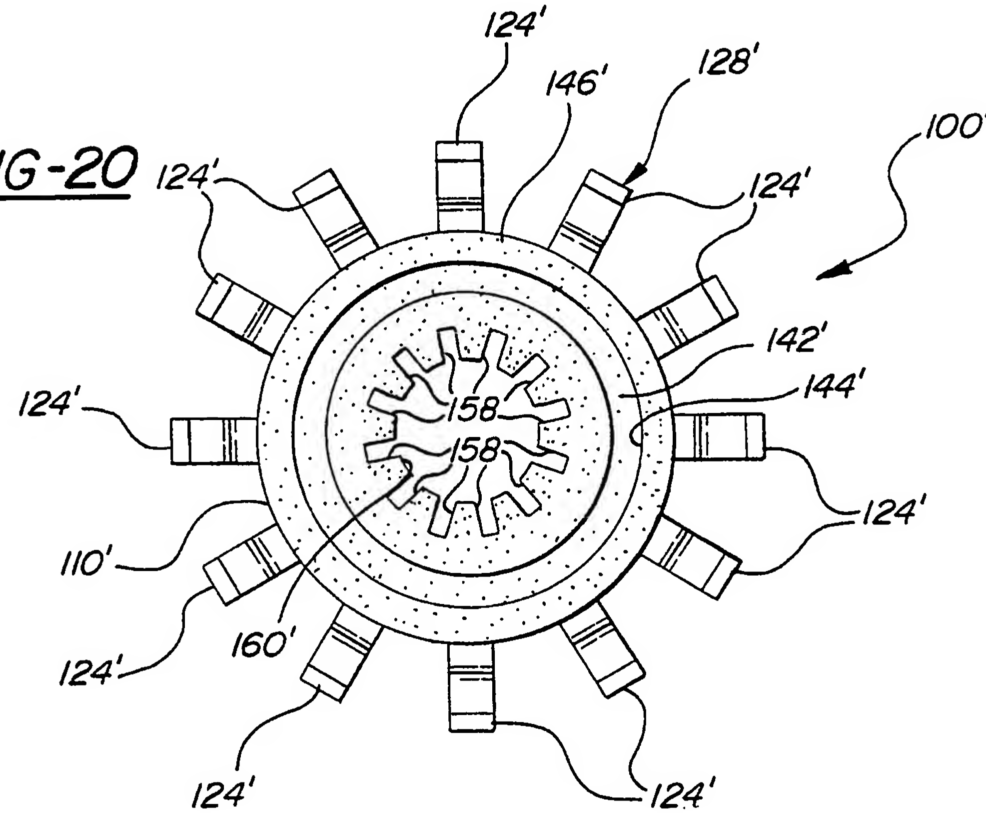

124'
128'
146'
100'
124'
124'
124'
142'
144'
124'
158
158
124'
110'
124'
160'
124'
124'

FIG-21

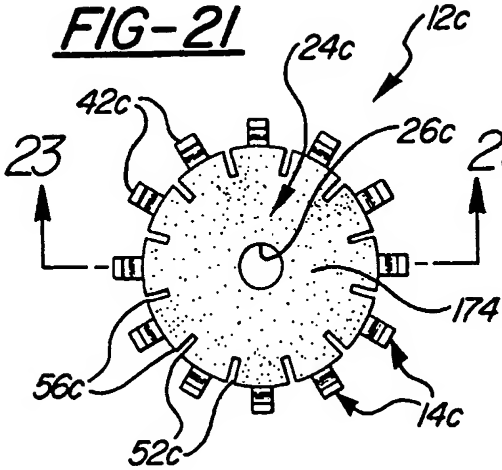


FIG-22

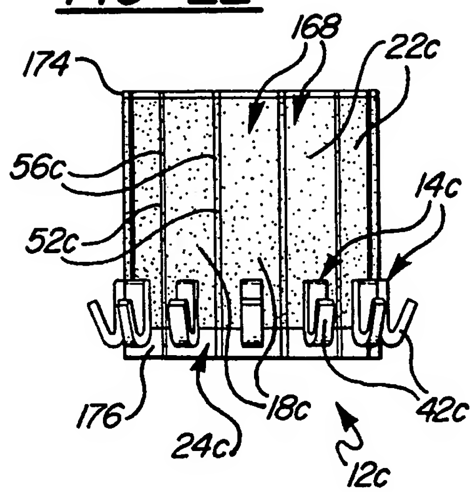


FIG-23

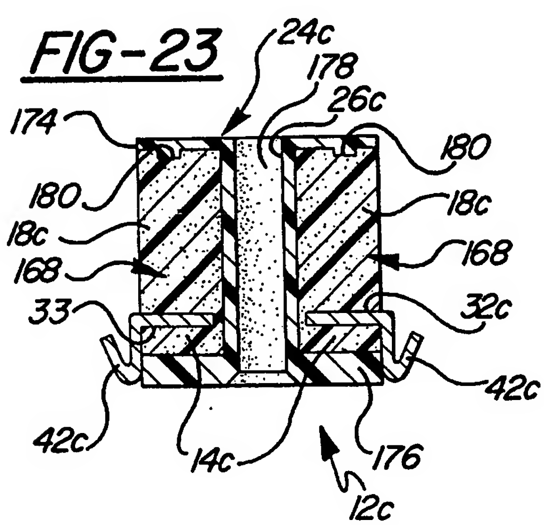
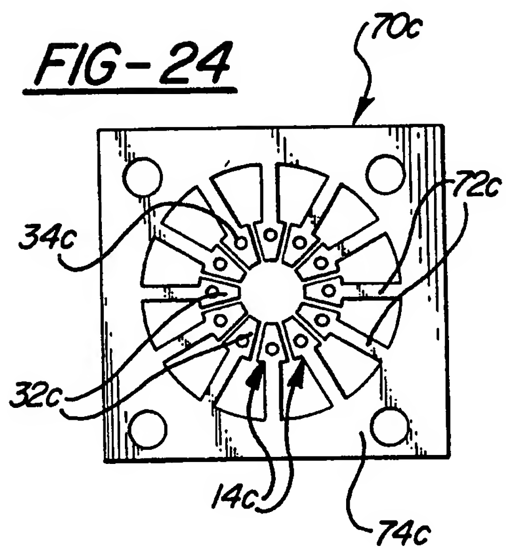


FIG-24



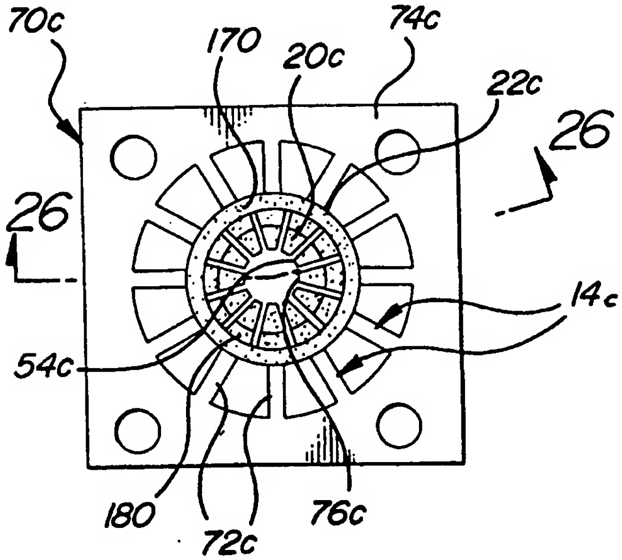


FIG-25

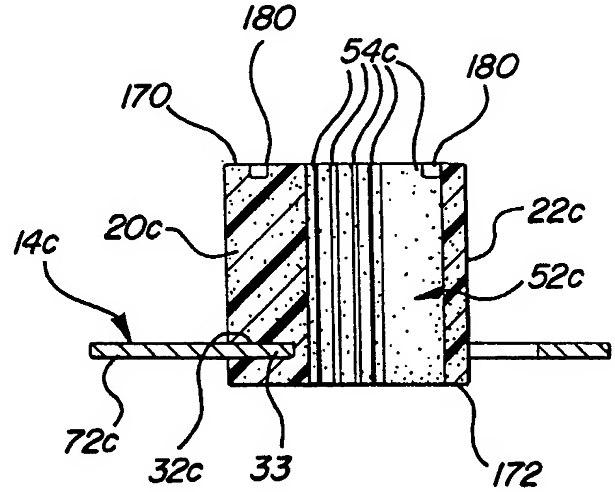


FIG-26

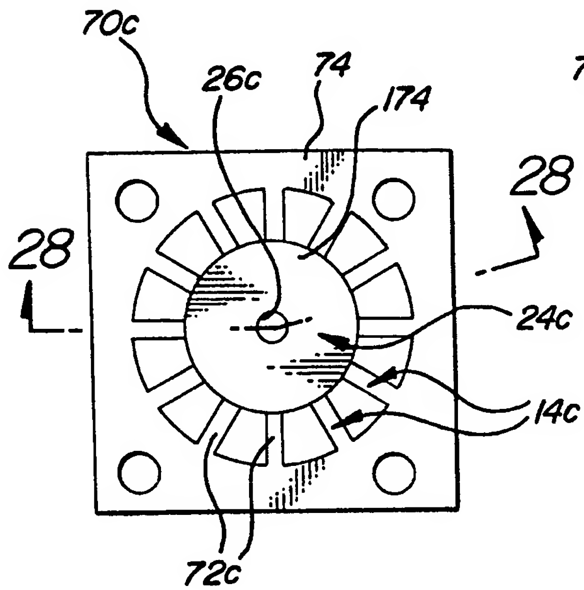


FIG-27

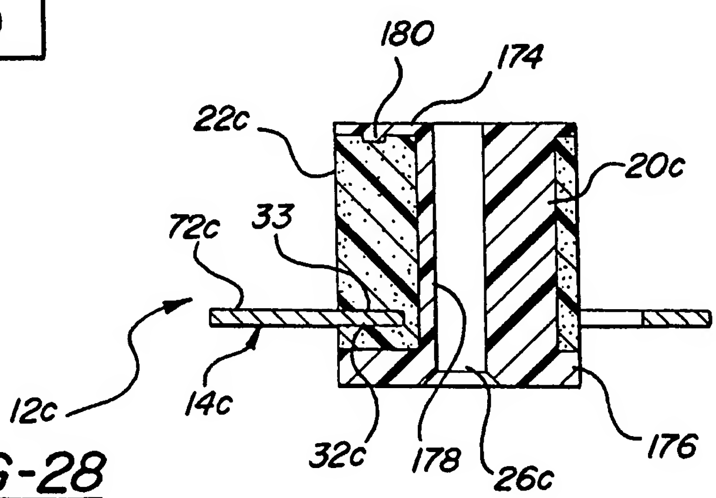


FIG-28

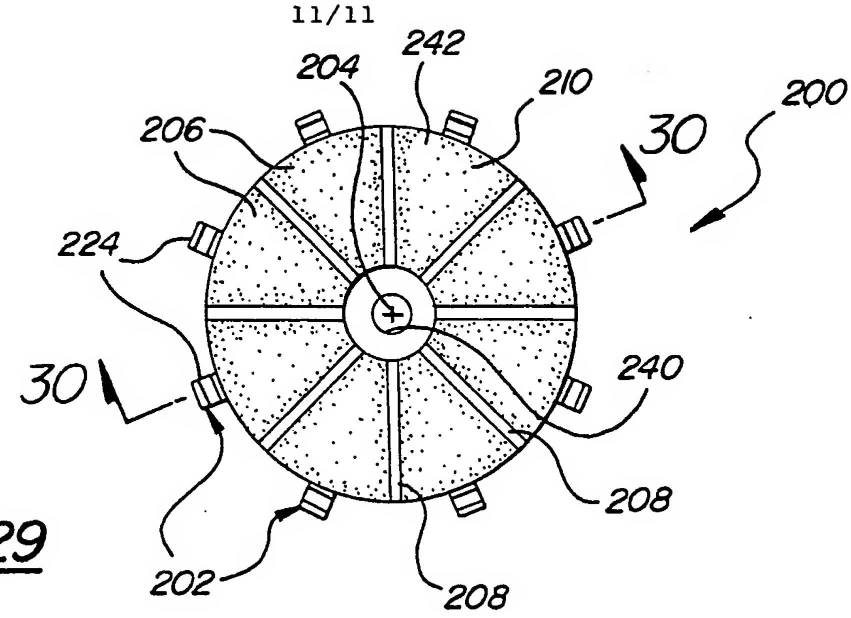


FIG-29

FIG-30

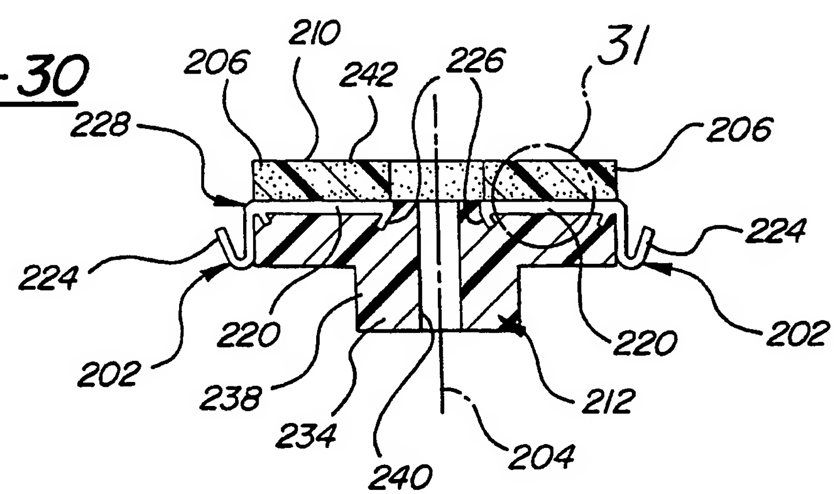
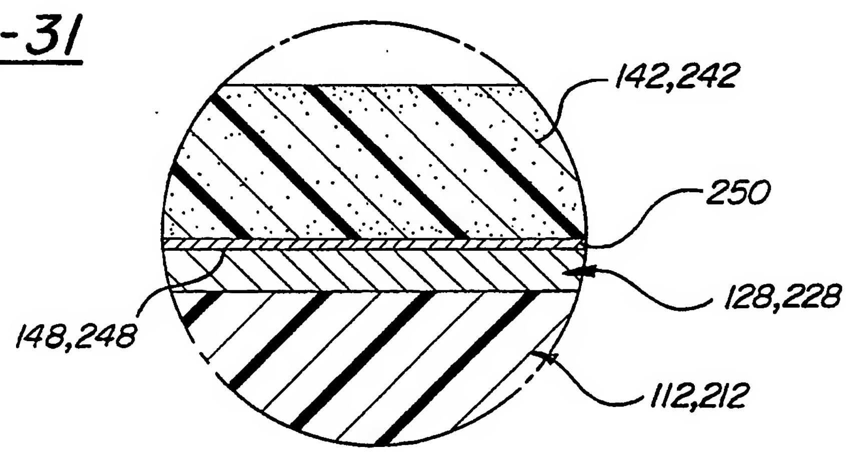


FIG-31



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/09579

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H02K 39/08, 15/00, 15/12; H01R 39/16, 39/04, 39/06, 43/06
US CL :310/233, 235, 236, 237, 42, 44; 29/597
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 310/233, 235, 236, 237, 42, 44; 29/597

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5,157,299 A [GERLACH et al] 20 October 1992 (20.10.92), Figures 1-2 and 5, Columns 6-8.	1-30
Y	US 5,255,426 A [FARAGO et al] 26 October 1993 (26.10.93) Column 3, Figures 1-2.	1-30
Y	US 5,175,463 A [FARAGO et al] 29 December 1992 (29.12.92), Figures 1-2, column 3.	1-30
Y	US 5,677,588 A [STROBL] 14 October 1997 (14.10.97) Figures 1-8, columns 4-5.	1-30
Y	US 5,552,652 A [SHIMOYAMA et al] 03 September 1996 (03.09.96) Figures 1-4, columns 3-5.	1-30

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
24 JUNE 1999	22 JUL 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	DANG DINH LE
Facsimile No. (703) 305-3230	Telephone No. (703) 308-1782

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/09579

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,864,821 A [ITO et al] 11 February 1975 (11.02.75) 2 Figures 1-7, columns 3-4.	31-59
Y	US 3,530,500 A [JENSEN] 22 September 1970 (22.09.70) Figures 1-5, columns 2-3.	31-59
Y	US 5,422,528 A [PRAHL] 06 June 1995 (06.06.95) Figure 1, column 3-4.	31-59
Y	US 3,983,431 A [HANCOCK] 28 September 1976 (28.09.76), Figures 2-5, column 6, lines 30-40.	31, 41